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(Continuing the Journal of the Allied Dental Societies)

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THE JOURNAL OF DENTAL RESEARCH

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A journal of stomatology; devoted to the advancement and dissemination of knowledge pertaining to the teeth and mouth, and to their relations to the body as a whole

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GENERAL ANNOUNCEMENTS

Proceedings of Dental Societies now Published as Independent Journals Within the Journal of Dental Research

Affiliated dental societies now publish their Proceedings on conditions that make each Society's group of papers, in effect, its own independent journal within the Journal of Dental Research. Reprints of these papers may be obtained for issuance in separate volumes of Transactions. The broad import of this development, for the cause of non-commercial journalism, will become apparent as it evolves in the successive issues. Information regarding the plan will be given to any society that may request it. All communications regarding the proceedings of societies should be addressed directly to the representatives of the respective organizations.

Papers Contributed by Dental Societies to this Number

First District Dental Society of the State of New York

This number consists of the paper awarded the Morris L. Chaim prize for 1925.

Important Books Received

The dentist's own book. By C. Edmund Kells, D.D.S., F.A.C.D., 1237 Maison Blanche, New Orleans. 1925: pp. 510; 7 5/8 x 4 5/8 in.; 116 illustrations; $7.50. C. V. Mosby Company, St. Louis, Mo.

The life and work of James Leon Williams. By George Wood Clapp, D.D.S., 220 West 42nd Street, New York City. With an introduction by C. N. Johnson, M.A., D.D.S., F.A.C.D., President of the American Dental Association, 1925: pp. 299; 7 1/4 x 3 3/4 in.; 114 illustrations. Dentists' Supply Company, New York City.

Pathology of the mouth. By Frederick B. Moorehead, M.S., D.D.S., M.D., Dean, and Professor and Head of the Department of Oral Surgery and Pathology, and Kaethe W. Dewey, M.D., Assistant Professor of Pathology, College of Dentistry, University of Illinois, Chicago. 1925: pp. 540; 6 3/4 x 4 1/8 in.; 213 illustrations; $7.00 net. W. B. Saunders Co., Philadelphia and London.

The technic of local anesthesia. By Arthur E. Hertzler, A.M., M.D., Ph.D., LL.D., F.A.C.S., Professor of Surgery, School of Medicine, University of Kansas, Kansas City, Kansas. *Third Edition.* 1925: pp. 272; 7 1/2 x 4 1/2 in.; 140 figures; $5.50. C. V. Mosby Company, St. Louis, Mo.

Principles of exodontia as applied to the impacted mandibular third molar. A complete treatise on the operative technic, with clinical diagnoses and radiographic interpretations. By George B. Winter, D.D.S., F.A.C.D., Professor of Exodontia, School of Dentistry, Washington University, St. Louis, Mo. 1926: pp. 835; 7 1/2 x 4 1/2 in.; 834 figures; $15.00. American Medical Book Company, St. Louis, Mo.

Applied biochemistry. By Withrow Morse, Ph.D., Professor of Physiological Chemistry and Toxicology, and Joseph M. Looney, M.D., Assistant Professor of Physiological Chemistry, Jefferson Medical College, Philadelphia, Pa. *Second edition.* 1927: pp. 988; 7 5/8 x 4 1/4 in., nearly 300 illustrations; $7.00. W. B. Saunders Company, Philadelphia and London.

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DELAY IN THE PUBLICATION OF THIS VOLUME

The successive numbers of this Volume were issued during the months of October, November, and December, 1927. See this *Journal*, Vol. VI, p. iii.

REPORT ON THE ENDOWMENT FUND OF THE JOURNAL OF DENTAL RESEARCH

The urgency of the effort to bring the publication of the numbers of the *Journal* up to date, as indicated in the foregoing announcement, has interfered with the preparation of a detailed statement of the present status of the Endowment Fund. There have been no important contributions since the publication of the report in Volume IV. During 1928, special attention will be given to enlargement of the Fund and to reports regarding it in the next volume.

PROCEEDINGS OF DENTAL SOCIETIES NOW PUBLISHED AS INDEPENDENT JOURNALS WITHIN THE JOURNAL OF DENTAL RESEARCH

Affiliated dental societies now publish their proceedings on conditions that make each society's group of papers, in effect, its own independent journal within the *Journal of Dental Research*. Reprints of sections may be obtained for issuance in separate volumes of transactions. The broad import of this development for the cause of non-commercial journalism in dentistry will become apparent as it evolves in successive issues. See the title page of this Volume, and compare it with that of Volumes V and VI.

NEW SCHEDULE OF PUBLICATION

In 1928 the *Journal of Dental Research* will be issued as a bi-monthly. The numbers will be prepared for distribution on or about the 15th of the months of February, April, June, August, October, and December. The subscription price will remain unchanged.

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ANTHROPOLOGICAL ASPECTS OF THE HUMAN TEETH AND DENTITION

WILTON MARION KROGMAN, Ph.B., M.A.

Department of Anthropology, University of Chicago

Awarded the Morris L. Chaim Prize for 1925, by the First District Dental Society of the State of New York

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[1] In the text the author does not follow closely, with headings or marginal letterings, the details employed in the "Contents" to emphasize the distinctions among the logical sub-divisions.—[*Ed.*]

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I. PREFACE

This paper is written, not for the anthropologist, but for the student of anthropology. To this end I have been compelled to include what may at first glance seem extraneous material, i.e., while the paper purports to consider the human teeth and dentition in the light of anthropological problems and technique, there has been included much material upon the development of the teeth and the origin of the human dentition. These physiological and historical data are, I think, a prerequisite to a firm grasp of the anthropological aspects of the human teeth and dentition.

It is the aim of this paper to present in logical and concise form the results of the many investigators who are working on the problem of

teeth considered as anthropological data. The bulk of the paper is, then, a compilation and analysis of the data available in this field. As a distinctly original contribution there will be found in the Appendix the results of an investigation of Melanesian dentition carried on by me at the Field Museum of Natural History, under the supervision of Dr. Fay-Cooper Cole. The bibliography of the paper is presented on pages 103–106.

I gratefully acknowledge the helpful criticism and kindly encouragement of Dr. Fay-Cooper Cole, of the Department of Anthropology of the University of Chicago; Dr. Milo Hellman, orthodontist, of New York City; Dr. Alfred S. Romer, of the Department of Palaeontology of the University of Chicago; and Dr. Newton G. Thomas, of the Dental School of the University of Illinois. In the revision of this paper I have benefited by the suggestions of Dr. W. K. Gregory, of the American Museum of Natural History; and of Dr. T. Wingate Todd, of the School of Medicine of Western Reserve University.

W. M. K.

University of Chicago,
July 6, 1926.

II. FOREWORD

One of the most recent approaches to the study of man's physical make-up, and one which promises to be very fruitful, is the study of the evolution and racial differentiation evinced by the human teeth and dentition. The recency of this mode of approach is attested by the fact that in 1911 Hrdlicka was able to say: "The type of human denture can be said to be today, with few exceptions, radically everywhere the same. . . . . The lack of pronounced racial differences in teeth or dentition indicates strongly a unity of origin of mankind." And, as late as 1921, Gregory asserted that "apart from a few striking cases . . . . racial characters in the teeth are at most not very conspicuous."[2] Investigation carried on since then has proved beyond a doubt that these statements were premature. Today, after the lapse of a few years, neither of these statements holds

[2] Gregory, 23; pp. 174–6. [Throughout the paper the author refers in this way to the Bibliography beginning on page 103.—*Ed.*]

true. The anthropologist has come to realize that the teeth and the dentition of man are of the utmost importance, both phylogenetically and ontogenetically. Gregory and Hrdlicka, themselves, together with such investigators as Hellman, Suk, Spier, and Sullivan, have demonstrated beyond question that the teeth are invaluable as racial criteria and links in the line of evolution.[3]

III. GROWTH OF THE TEETH

1. Development of the teeth

Wiedersheim[4] has thus briefly summed up the development of the teeth:

"The teeth are developed quite independently of the endo-skeleton, and both ectoderm[5] and mesoderm take part in their formation. The first traces of the teeth are seen primarily in the form of superficial papillae of the mucous membrane; but secondarily, owing to want of space, the epithelium of the mouth grows inwards so as to give rise to a dental lamina, which becomes enlarged distally at certain points to form the so-called enamel-organs. These, as they grow deeper into the mesoderm, become bell-shaped, and enclose modified masses of connective tissue, the dental papillae; the upper cells of the papillae, i.e., those next to the enamel-organ, are known as odontoblasts (*fig. 1, A*). The epithelial and connective-tissue germs come into the closest relation with one another, and give rise respectively to the calcified enamel with its 'cuticuladentis' and to the dentine of which the teeth are composed. The dentine consists of calcified hard dentine and vascular vaso-dentine. The enamel is the harder and contains little organic matter, and the dentine (ivory) is permeated by a system of fine canals into which delicate processes of the odontoblasts extend. A third, bone-like substance, the cement, is also formed from the mesoderm around the bases of the teeth and between the folds of enamel when these are present; it may unite with the bones of the jaw. The root of the tooth, embedded in the gums, is provided at its

[3] It is noteworthy that Miller points out that, with the exception of Neanderthal, of which the entire skeleton has been found, most of the important finds of fossil men and apes consist principally of teeth and fragments of mandible and maxillary bones. Miller, 6; p. 215.

[4] Wiedersheim, 49; pp. 313–14.

[5] Embryologically *ectoderm* is a layer of cells giving rise to cutaneous structures, nervous system, eyes; *mesoderm* gives rise to muscles, bones, blood vessels, etc.; *entoderm* gives rise to the gut and all its derivatives, such as liver, pancreas, etc.

lower end with an opening leading into the central pulp-like cavity (*fig. 1, B*), containing the pulp of the tooth, which consists of cells, blood-vessels, and nerves, and which renders the tooth sensitive."

The foregoing sketch[6] purports to illustrate the development of the tooth. Thomas[7] has pointed out it is only one of many ways in which the tooth may, and actually does, develop. To quote him: "The dental band or lamina is a most variable structure. Figures 1, 2, 3 and 4 (*fig. 3* of the *original* is shown *here* as *fig. 1*, A) are

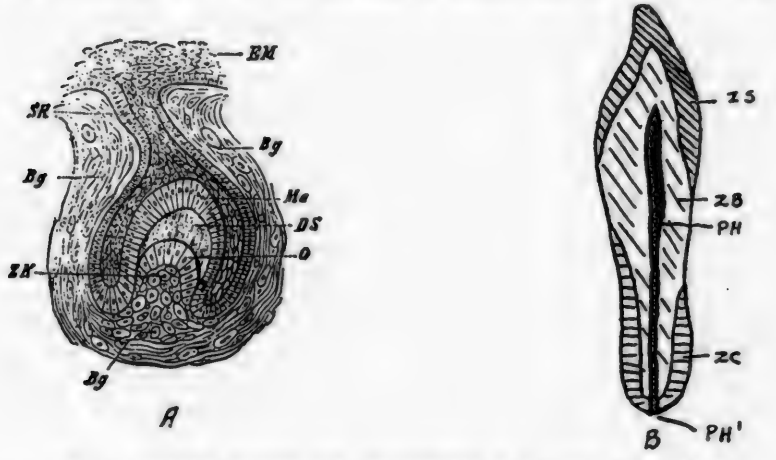

FIG. 1. DIAGRAMS SHOWING THE DEVELOPMENT OF A TOOTH (Wiedersheim)

BG—Connective tissue follicle, or sac surrounding the tooth. *DS*—Dentine. *EM*—Epithelium of mouth. *MA*—Enamel epithelium. *O*—Odontoblasts. *SK*—Dental lamina. *ZK*—Dental papilla. *PH'*—Aperture of pulp cavity (PH). *ZB*—Dentine. *ZC*—Cement. *ZS*—Enamel.

often used to depict the process of development, but they fall embarrassingly short of showing what actually occurs. . . . . These artifices present the burrowing column of cells perpendicular to the oral surface, and as a usual procedure it is discussed as though it were the sole determinant of its directional destiny. The fact that the total environment of this flexible, labile structure is in a surge of activity seems lost to consideration." With these words of warn-

[6] Wiedersheim, 49; pp. 313–14.
[7] Thomas, 46; p. 3 ff.

TABLE 1

Chronology of the dental follicle in man

	DESIGNATION OF THE FOLLICLES	PLACE OF THE ORIGIN OF THE EPITHELIAL CORD	PERIOD AT WHICH THE ENAMEL-ORGAN FIRST APPEARS	PERIOD AT WHICH THE DENTAL BULB APPEARS	TIME OF THE APPEARANCE OF THE FOLLICULAR WALL	CLOSING OF THE FOLLICLE AND RUPTURE OF THE CORD	PERIODS AT WHICH THE DENTINE-CAP FIRST APPEARS	PERIODS AT WHICH THE TEETH ARE ERUPTED	PERIODS AT WHICH THE TEETH ARE NORMALLY SHED
								month	*year*
TEMPORARY DENTITION	Inf. cent. incis.	Epithelial lamina	From 7th–8th week	9th week	10th week	Beginning of the 4th month	16th week	6	7
	Sup. cent. incis.							10	7.5
	Inf. lat. incis.							16	8
	Sup. lat. incis.							20	
	Inf. cuspids							30–32	12
	Sup. cuspids								
	1st inf. molars						17th week	24	10
	1st sup. molars							26	10.5
	2nd inf. molars							28	11
	2nd sup. molars							30	11.5
								year	
PERMANENT DENTITION	Inf. cent. incis.	Cord of the corresponding temporary teeth	About the 16th week	20th week	21st week	9th month	1st month after birth	7	
	Sup. cent. incis.								
	Inf. lat. incis.							8.5	
	Sup. lat. incis.								
	Inf. cuspids							11–12	
	Sup. cuspids								
	1st inf. bicuspid	Cord of the corresponding temporary molars						9–10	
	1st sup. bicuspid								
	2nd inf. bicuspid							11	
	2nd sup. bicuspid								

TABLE 1—*Continued*

PERMANENT DENTITION	1st inf. molar 1st sup. molar	Epithelial lamina	15th week	17th week	18th week	20th week	6th month of fœtal life	5–6	
	2nd inf. molar 2nd sup. molar	Cord of 1st perm. molars	3rd month after birth	1st year	1st year	1st year	3rd year	12–18	
	3rd inf. molar 3rd sup. molar	Cord of 2nd perm. molars	23rd year	After 6th year	After 6th year	After 6th year	12th year	18–25	

ing we may view the illustration as but one mode of development. There are others, but the writer being an anthropologist, and not a physiologist, cannot portray them. The great fact of development remains, however.

Tomes[8] points out that on "about the fortieth or forty-fifth day of intra-uterine life, in the situation corresponding to the future alveolar border, there appears in transverse sections an ingrowth of epithelium extending along the whole length of the jaw, rounded on its deeper aspect." This is the primitive tooth-band or "Zahnleiste." "About the same time that the tooth-band becomes differentiated, an ingrowth of epithelium takes place all around the outer surfaces of the jaws in the situation which is to be occupied by the vestibulum oris, or groove between the lips, and cheeks and the jaws." By the forty-eighth day the tooth-band is divided into two parts, one going to the lip, the other to the tissues beneath. Soon after, near "the free edge of the tooth-band, small club-shaped thickenings appear at each point where a tooth is about to be formed. Soon each cellular accumulation assumes a bell-shape, into the concavity of which a papilla-like specialization of the submucous tissue grows." At about the ninth week of intra-uterine life tooth-germs appear "at detached points only, where teeth are going to be found." The development from this point is one similar, not identical, to that above described by Wiedersheim.

Magitot[9] has done by far the most comprehensive work on this problem; viz., the development, in utero, of the tooth-germ and the subsequent tooth arising from that germ. His conclusions are as follows (see also *table 1*):

(1) The dental follicles first appear as a cord emanating from the epithelial layer of the oral mucous membrane.

(2) The cords that give origin to the follicles of the first dentition arise directly from a process of the oral epithelium (epithelial band and epithelial lamina). The cords for those permanent teeth which succeed the temporary ones are diverticula or outgrowths from the

[8] Tomes, 48; pp. 134–145. For fœtal calcification see Tables 4 and 5, pages 18 and 20, respectively. Andrews, 31, pp. 356–8, substantially agrees with Tomes's outline of the development.

[9] Le Gros and Magitot, 38 C; pp. 160, 181–4.

primitive cords. As for the cords of the other permanent teeth, those for the first molars originate directly from the epithelium of the mucous membrane, and the remaining ones (eight in number) from the cords of the preceding molars (*table 1*).

(3) The cord, whatever may be its point of origin, is invariably epithelial. It is composed outwardly of a layer of prismatic elements of the Malphigian stratum; and in the interior, of polyhedric epithelial cells.

(4) The extremity of the cord, which soon takes the form of a club-shaped swelling, constitutes the *enamel-organ* of the future follicle.

(5) The *dental bulb* appears spontaneously in the midst of the embryonic tissue and at a point in immediate proximity to the deeper face of the enamel-organ.

(6) The enamel-organ covers the bulb, serving as a cap for it, an arrangement which continues during all the periods of evolution, preceding the formation of the dentine and the enamel.

(7) The follicular processes emanate directly from the elements of the bulb, and rise from its base to the summit of the follicle, where they unite and constitute the follicular sac.

(8) Synchronous with the closing of the follicles is the rupture of the cord. From this period the follicle loses all connection with the epithelium of the mucous membrane. The formation of the follicle is now complete.

(9) The evolutionary phenomena of the follicles in both dentitions are identical as to their nature. The only perceptible differences are the exact points from which the epithelial cords originate, and the length of time necessary to accomplish their successive phases of evolution.

(10) The mode of evolution of the dental follicle and of the pileous follicle is identical.

Tomes,[10] basing his conclusions mainly upon Röse's work, offers the following:

(a). First appearance of the dental lamina takes place from the thirty-fourth day to the fortieth day of intra-uterine life.

(b). About the tenth week the anterior eight papillae form and

[10] Tomes, 48 A; pp. 204–6.

TABLE 2

Dates at which the several structures appear in the human embryo

(From Tomes, 8 ed., adapted from Röse)

LENGTH OF EMBRYO	AGE	COMMENT
12–15 mm.	34–40 days	First appearance of epithelial inflection. First trace of Meckel's cartilage, but as yet no trace of bone
17 mm.	48 days	The inflection has (according to Röse) divided into the Lippenfurchenleiste and the Zahnleiste. Deepest layers of epithelium have become cylindrical. Meckel's cartilage fully developed, and first traces of bone appear
2.5 cm.	9 weeks	The Zahnleiste shows alternate enlargements and depressions
3.2 cm.	10 weeks	The enlargements are club-like, and the dentine-papillæ are growing into them. Eight papillæ are present
4 cm.	11½ weeks	In each jaw all the ten papillæ are found. The lip groove has deepened by the disappearance of the upper part of the epithelium which filled it
11.5 cm.	14 weeks	The milk tooth germs lie like swallow's nests against the Zahnleiste, from which they are now partly pinched off. First appearance of stellate reticulum. Behind the last temporary molar the Zahnleiste runs backward into the mesoderm without as yet a vertical connection with the surface epithelium above

		DECIDUOUS TEETH					PERMANENT TEETH							
		Median incisor	Lateral incisor	Canine	First molar	Second molar	Median incisor	Lateral incisor	Canine	First premolar	Second premolar	First molar	Second molar	Third molar
18 cm.	17 weeks	The necks of the enamel-organs of the front teeth are greatly reduced in size; those of the back teeth, still broad. Zahnleiste irregularly thickened, and in front fenestrated. The dental groove formed in front of mouth										Dentine-papillae formed		
24 cm.	20 weeks	Dental groove extends to back of mouth. First trace of calcification in the incisors										Trace of tooth sac		
30 cm.	24 weeks	In front of mouth much fenestration of Zahnleiste. Trace of calcification in canines and temporary molars					Papillæ embraced by enamel-germ		First trace of papillæ			Enamel-germ fully developed		

TABLE 2—*Continued*

36 cm.	29 weeks	In the temporary molars there is calcification on each of cusps, but these are not yet united with one another			Cusps united		Trace of tooth sacs			Zahnleiste thickened	Trace of enamel-germ	No calcification as yet		
		LENGTH OF CAPS OF DENTINE AND ROOT												
	Fœtus, 9 months	4.5 mm.	4 mm.	2.5 mm.	2.5 mm.	3 mm.	No calcification					Caps on cusps		
	Child, 4 months	Root, 0.5 mm.	5 mm.	4.5 mm.	3–4 mm.							4 cusps, 1–2.5 mm.	Bud on Zahnleiste	
	6 months	Root, 3.5 mm.	Root, 0.5–2.5 mm.	Root, 0.5 mm.	4–5 mm.	3–4.5 mm.	Cap, 3 mm.	Cap, 2.5 mm.	Cap, 1 mm.			Caps, 2–3.5 mm.	Papillæ	
	2 years												4 cusps, cap, 1.5–2 mm.	
	3½ years	Root, 11 mm.	Root, 11 mm.	Root, 11 mm.	Root, 8–9 mm.	Root, 6–7 mm.	Crown complete	Cap, 7 mm.	Cap, 8–9 mm.	Cusps united. Caps, 5–6 mm.	Cusps separate. Caps, 1–2.5 mm.	Root, 1.5 mm.	Caps, 2 mm.	End of Zahnleiste thickened
	5 years													Papilla of third permanent molar entering into its enamel-organ

become embedded in their respective enamel-organs, the remaining two following in a week or so. The separation of their enamel-germs from the tooth-band begins about the fourteenth week.

(c). In the fourteenth week the tooth-band extends beyond the lowest temporary molar, and about the seventeenth week the papilla of the first permanent molar becomes developed.

(d). In the sixth month after birth the beginnings of the second molar appear.

(e). At about three and a quarter years the commencement of the third molar is seen.

These data are graphically presented in a table prepared by Tomes, after Röse, showing the dates at which the several structures appear in human embryos (*table 2*).

2. Deciduous teeth

Man, as we have observed, is diphyodont, i.e., he has two sets of teeth; a primary deciduous or "milk" set, and a permanent successional set.[11] The teeth are embedded in the alveolar processes of the maxillae and mandibulae. They are implanted in the alveoli, or "sockets," by a form of articulation known as gomphosis.[12] A tooth consists of a crown, a neck, and a root or roots. The crown is above the gum, the root is implanted in the alveolar socket, and the neck is the region at or near the gingival trough.[13] The tooth is composed of four tissues: enamel, covering the crown; dentine, forming the body of the root and the crown; cementum, which covers the root and joins the enamel at the neck; pulp tissues, which fill the central cavity of the dentine.[14] The gums are soft tissues covering the alveolar processes and gripping the neck of the teeth. "They are composed of connective tissue, containing many white fibres intermingled, forming a firm membranous mass, continuous with the periosteum beneath, and with the peridental membrane at the necks of the teeth. They are covered with a stronger outer coat of squa-

[11] Bolk, 14, would class the first permanent molar with the deciduous teeth, while Wiedersheim, 49, p. 319, would class all the permanent molars with the deciduous teeth.

[12] Duckworth, 20; p. 278; Owen, 41, I; p. 300; Hopewell-Smith, 28; pp. 126–7.

[13] Black, 13; p. 176.

[14] *Ibid.*, p. 2.

mous epithelium. They are richly supplied with blood-vessels and nerves."[15]

The foregoing statements apply to both deciduous and permanent teeth. We may now note another fact which both have in common, viz., eruption. In order to come to the surface, the teeth go through the process known as "eruption," a literal breaking out upon the surface. This phenomenon is one upon which many have speculated, and it will be our task, for the next few pages, sketchily to survey the problem.[16] Hopewell-Smith[17] has laid down the following general rules governing eruption:

(1) Teeth of the same denomination appear in pairs.
(2) From the point of view of time, those of the lower jaw precede those of the upper jaw.
(3) The first deciduous incisors precede the second, the latter the first molars, after which come the second molars, or perhaps the canines.

The teeth erupt in the following order (Bean, 12; p. 300):

(a) Lower first molars
(b) Lower median incisors
(c) Upper first molars
(d) Upper median incisors
(e) Lower lateral incisors
(f) Upper lateral incisors
(g) Upper median premolars
(h) Lower canines
(i) Lower median premolars
(j) Upper lateral premolars
(k) Upper canines
(l) Lower lateral premolars
(m) Lower second molars
(n) Upper second molars
(o) Lower third molars
(p) Upper third molars

Lede[18] has made a very thorough study of the eruption of the deciduous teeth, and in addition presents some very interesting conclusions on the effect of nourishment (*table 3*). Hopewell-Smith[19] says, of eruption, that "there is only one real explanation, i.e., that eruption is a normal physiological process, governed by the same forces which are acting on the other parts of the body." At the

[15] Black, 13; p. 155.
[16] For periods or times of eruption see Table 7.
[17] Hopewell-Smith, 28; p. 288.
[18] Lede, 38 B; pp. 204–8.
[19] Hopewell-Smith, 28; pp. 21–22, and 290 ff. Cf. Tomes, 48; p. 238 ff.

same time he notes the various *theories* which likewise attempt to explain the mechanism of eruption:

1. Radicular elongation. As tooth grows (i.e., as root grows) it is pushed to the surface.
2. "Bone currents." Interstitial growth of bone occasions the movements of the developing teeth.

TABLE 3

Eruption of the teeth of the first dentition

	INFANTS OF WET NURSES WITHOUT NURSELINGS		INFANTS OF WET NURSES WITH NURSELINGS		NURSELINGS		INFANTS FED ARTIFICIALLY		GENERAL AVERAGE	
	Months	Days	Months	Days	Months	Days	Months	Days	Months	Days
Lower jaw										
Incisor, median, right	7	19	8	8	9	—	9	24	8	4
Incisor, median, left	7	23	8	20	9	—	9	25	9	8
Incisor, lateral, right	13	—	13	12	14	9	15	16	14	20
Incisor, lateral, left	13	5	13	14	14	18	15	3	14	18
Canine, right	18	11	19	5	19	12	20	9	19	29
Canine, left	18	24	18	24	19	14	20	7	19	26
Anterior premolar, right	15	21	15	26	16	25	17	12	16	13
Anterior premolar, left	15	21	15	17	16	16	17	11	16	26
Upper jaw										
Incisor, median, right	9	15	10	10	10	25	12	19	10	24
Incisor, median, left	9	13	10	6	11	5	11	21	10	19
Incisor, lateral, right	11	3	11	28	11	29	15	16	14	20
Incisor, lateral, left	11	8	12	1	11	27	13	15	12	3
Canine, right	18	18	18	23	18	23	19	24	18	29
Canine, left	18	19	18	21	18	20	19	27	18	23
Anterior premolar, right	14	28	15	2	16	17	16	23	15	25
Anterior premolar, left	14	20	15	1	15	24	16	24	15	17

3. Deposition of bone. Deposition of bone at the base of dental crypts and contraction of alveolar plates cause eruption.
4. Blood pressure. Blood pressure in vascular tissues between the developing tooth and its surroundings cause eruption.
5. "Epithelial." The epithelium is the determining factor in directing the tooth to its fixed position in the jaw.

6. Gubernaculum. Disproportionate growth of the tissues forming the tooth and of the tissues surrounding the tooth causes eruption.
7. Epiblastic. Enamel, being epiblastic in origin, should, like other dermal tissues, have an inherent tendency to come to the surface.
8. Addition of dentine. Lengthening of the extremities of the roots, by the addition of dentine, causes eruption.
9. Influence of nutrition. It is believed that nutrition has some effect upon the erupting crowns.[20] Some change occurs in the gums and in the walls of the dental crypts—possibly there is a withdrawal of a certain amount of the blood supply of neighboring parts through great activity in growth of the dental follicle just preceding and during the period covered by the process of the extension of the crown.

Hellman[21] very clearly stated the position of the last mentioned theory when he wrote:

"The process of dentition is a physiological manifestation of growth and is subservient to the variations in rate, acceleration, and retardation. The acceleration in body growth may be accompanied by a retardation in the process of teething and vice versa. Excessive retardation in body growth may result in diminution in size. Excessive retardation in dentition may result in abnormal position and consequent malocclusion. It may therefore be concluded that nutrition has a direct, positive, and stimulating effect upon body growth as a whole, but it appears that the acceleration in body growth has an adverse influence upon the process of dentition."

Turning now to a description of the deciduous teeth we may note that, taken by and large, the external configuration of both deciduous and permanent teeth is much the same.[22] The deciduous teeth are much smaller, however, especially the anterior teeth. The crown is smaller, the root shorter, and the neck more constricted. The deciduous teeth are easily distinguished from the permanent teeth

[20] It is to be noted that malnutrition may hasten eruption, but that the teeth thus erupted are invariably deficient in any one or all of their component parts, and seldom if ever are long-lived.

[21] Hellman, 25 B.

[22] Hopewell-Smith, 28; p. 222 ff. Cf. Todd, 47; p. 241 ff.

as follows: (1) the incisor and canine deciduous teeth are smaller while the deciduous premolars are larger; (2) their crowns, molars especially, are much rounder; (3) their color is much paler than the permanent teeth.[23] The *incisors* are very conical, with no pronounced angles. At birth the cutting edge tends to be trilobed, but the tubercles quickly disappear as a consequence of attrition. The roots of the maxillary teeth are conical, those of the mandible teeth flattened mesially and distally. The first maxillary and second mandibular teeth are the largest. One may discriminate between the maxillary and mandibular teeth by noting that the distal angle of the former is the more obtuse. The *canines* have conical crowns, while the surfaces are much as in the permanent canines. The neck is in more of a horizontal plane than the incisors. The upper and lower teeth may be differentiated by the fact that the lower are slightly smaller. As in the incisors we cannot discriminate as to right and left. The *second molars* resemble closely the true permanent molars,[24] with the exception that the crowns tend to be shorter. The second molar is much larger than the first. In the maxilla the cusps on the lingual side are more elevated than the others, while the reverse is true in the mandible. The roots are three in number, widely divergent in the first molar, less so in the second. The first maxillary molars are triangular and have three cusps; the second maxillary molars have four cusps with an oblique ridge between the metacone and protocone. The first mandibular molar is flattened labiolingually, and has three cusps. The second possesses five cusps, a fact which renders it easy to identify.

The deciduous teeth vary little, the average widths of the crowns on their labial surfaces, taken in mm., being as follows (see also *table 6*):[25]

e	*d*	*c*	*b*	*a*	*a*	*b*	*c*	*d*	*e*
8.6	6.8	6.6	5.3	6.2	6.5	5.2	6.6	6.8	8.5
9.4	7.8	5.7	4.4	3.8	3.8	4.4	5.6	7.7	9.6

[23] Black, 13; p. 98.
[24] Wiedersheim, 50; p. 160; Gregory, 23; p. 470.
[25] Dewey, 19B; p. 35.

Variations may occur (mm.): first incisors, 5.6–7.0; second incisors, 4.2–6.0; canines, 5.7–7.1; first molars, 6.0–7.5; second molars, 6.7–9.0.[26]

3. Permanent teeth

For the descriptive data the reader is referred to *tables 4, 5 and 8*, showing respectively the right maxillary and mandibular permanent teeth. For periods of eruption see *tables 4, 5 and 7*.[27] See page 72 for the racial aspects of the eruption of the teeth.

The transition from the deciduous to the permanent teeth is accompanied by a process of absorption. This absorption is consummated, "it is generally believed, by means of a special tissue to which the name 'absorbent organ' has been applied. It is, here, a physiological process, assisted by the gradual development and eruption of the successional teeth. . . . . This absorption is caused by a process of hyperemia, the effect of which is alternately to absorb old and to produce new bone."[28] We may also note the fact that man is tending to reduce the number of his teeth, especially the molars.[29] According to Duckworth,[30] the lateral incisors are also disappearing. Also, one of the premolars shows a tendency to disappear. Thus the dental formula of the future may read:

$$I\ \frac{1}{1}\ C\ \frac{1}{1}\ Pm\ \frac{1}{1}\ M\ \frac{2}{2}$$

The permanent teeth are of such great importance anthropologically that further discussion concerning them, especially with reference to the form of the arch, the palate, the racial aspects of the eruption of the teeth, etc., appears on pages 69–85.

[26] Taken from Hopewell-Smith, 28; p. 226.

[27] The data were taken mainly from Hopewell-Smith, 28; Tomes, 48; Dewey, 19B, Owen, 41 (I); Black, 13. It will be found that Hopewell-Smith is based to a great extent on Tomes and Black.

[28] Hopewell-Smith, 28; pp. 130–1.

[29] Wiedersheim, 49; p. 319; Duckworth, 20; pp. 269–71.

[30] Duckworth, 20; pp. 269–71. See also Hrdlicka, 2; p. 175, who notes degeneration of the upper lateral incisors as follows: American whites—♂ 3 + per cent; ♀ 3 − per cent. Negroes—♂ 3 − per cent; ♀ 4 + per cent. Chinese—"twice as frequent as in the whites in the males, and also perceptibly more frequent in females." Japanese —"there is also a higher proportion of the condition present in the Japanese."

TABLE 4

Anatomical characteristics of the permanent mandibular teeth (right side)

CRITERIA	MEDIAN INCISOR	LATERAL INCISOR	CANINE	FIRST PREMOLAR	SECOND PREMOLAR	FIRST MOLAR	SECOND MOLAR	THIRD MOLAR
Mean measurements	From apex to edge, is 23 mm,; width at neck, 6 mm.; longer mesially than distally. Varies: 18–27.5 mm.; 3–5.5 mm. across incisive edge *Black:* Crown, 0.34 in.; root, 0.47 in.; total, 0.81 in.	Extreme length, 24.5 mm.; width at edge 6 mm. Varies: 17–27 mm. length; 5.5–6 mm. width at edge *Black:* Crown 0.35 in.; root, 0.50 in.; total, 0.85 in.	Extreme length, 31 mm.; width 12 mm. Varies: 22.5–33.5 mm. length; 6–12 mm. width. *Black:* Crown, 0.40 in.; root, 0.60 in.; total, 1.00 in.	Extreme length from summit of cusp to apex, 25 mm.; mesio-distal width across crown, 7 mm. Varies: 7–8 mm. width; 18–28 mm. length *Black:* Crown, 0.30 in.; root, 0.54 in.; total, 0.84 in.	Extreme length, 23 mm.; labio-lingual coronal width, 8 mm. Varies: Length, 20–25 mm.; width, 7.5–8.5 mm. *Black:* Crown, 0.31 in.; root, 0.56 in.; total, 0.87 in.	Extreme length from apex to external cusp, 21 mm.; greatest coronal width, 12 mm. Varies: 17–28 mm.; 7–13 mm. *Black:* Crown, 0.30 in.; root, 0.52 in.; total, 0.82 in.	Extreme length from apex of mesial root to crown, 23 mm.; width across buccal surface of crown 11 mm. Varies: 21–24 mm.; 10.5–11.5 mm. *Black:* Crown, 0.28 in.; root, 0.50 in.; total, 0.78 in.	Greatest diameters, 10–16 mm. in coronal region. Varies: 14–18 mm.; 8–12 mm. *Black:* Varies, tooth to tooth
Coronal surfaces and angles	*Crown:* Cone-shaped, base compressed side to side, apex flattened mesio-distally *Labial:* Triangular, with edge as base; convex in both directions; angles acute; may have double vertical grooving *Lingual:* Concave in both planes, more so mesio-distally; also tri-angular, apex at gingival margin *Mesial:* Flat, tri-angular; concave above down-wards; convex labio-lingually *Distal:* Triangular and concave-con-vex as in mesial; shorter and smaller than mesial; widest at edge; angles acute	*Crown:* More fan-shaped than I_1 *Labial:* Triangular, apex downward; convex both directions; may have vertical groove; upper border longer than I_1 *Lingual:* Concave side to side and some above downward *Mesial:* Tri-angular, base below; slightly concave; junction with neck indistinguishable *Distal:* Triangular; concave both directions	*Crown:* Cone-shaped, flat-tened, but more on labial and lingual sides *Labial:* Convex both directions; much pitted and grooved, es-pecially anteri-orly and posteri-orly *Lingual:* Concave side to side and some above down; vertical ridge, making anterior part larger than posterior *Mesial:* Broader than distal; shape of blunt triangle, base at gum margin; flat, hardly convex *Distal:* Not so broad as mesial; more convex; in lower part some concave both ways	*Labial:* Pentagonal shape; convex mesio-distally and above down; may be pitted in horizontal bands; widest between its two superior angles *Lingual:* Convex, very small; tubercle formed by cingulum *Mesial:* Quad-rangular, en-croached upon by convex labial surface *Distal:* More con-cave than mesial; mesial angle large in upper part *Morsal:* Triangu-lar; apex is lingual; edges rounded and well marked; three transverse ridges; two pits; one distal, one mesial (may be connected)	*Labial:* Larger, and mesial and distal angles more ac-centuated than in PM_1, but it is not so "bent," as in PM_1, nor so convex *Lingual:* Flat-tened, rectangu-lar; width greater than height; upper border shows cusp ele-vation *Mesial* and *Distal:* very convex; upper mesial border sharper than in distal *Morsal:* Quad-rangular; pitted mesially and dis-tally as in maxil-lary PM^2	*Buccal:* Larger than lingual; convex side to side and above down; "bent" as in PM_1, and PM_2; divided by three points antero-posteriorly; amelo-cementum junction clear *Lingual:* Quadran-gular; less convex than buccal *Mesial:* Tri-angular; with base at the neck; convex both direc-tions; Flatter than distal *Distal:* Triangular; convex both directions; lower border not sepa-rated from root *Morsal:* Trape-zoidal; 5 cusps and 5 fissures (no paracone); fis-sures are mesial, disto-buccal, mesio-buccal, distal, lingual	*Crown:* Quadri-lateral, rounded, symmetrical *Mesial:* Same as M_1, except ex-ternal border more sloped *Buccal:* Resembles distal *Lingual:* Less ex-tensive and flat-ter than buccal *Distal:* Same as M_1, but more convex and rounded *Morsal:* 4 cusps, 4 fissures; 2 an-terior, 2 posterior fissures; cusps at angles; fissures deep	*Crown:* Hard to describe; no two alike. In gen-eral, *Distal* and *Buccal* surfaces are most convex, *Mesial* flattest, with *Lingual* intermediate; whole crown has rounded angles and surfaces; cusps slightly elevated; fissures and pits on *Morsal* surface shallow

TABLE 4—*Continued*

Neck	*Neck:* Inconspicuous, blended with root	*Neck:* Inconspicuous mesially and distally; visible labially; marked lingually	*Neck:* More pronounced labially and lingually than mesially and distally	*Neck:* Inconspicuous; in horizontal plane	*Neck:* Lies in horizontal plane	*Neck:* Hardly visible; lies in horizontal plane; quadrangular	*Neck:* Lies in horizontal plane and is well marked	*Neck:* Similar to M_2
Roots	*Root:* Long, narrow mesio-distally, flattened laterally; broad and convex mesially; thin and pointed distally; mesially convex side to side; no groove; distally is concave in both planes and vertically grooved	*Root:* Similar to I_1, but labially and lingually tends to be of equal width; apex acute; grooved distally; may be two roots	*Root:* Long, broad gingival margin and tapers to apex; inclined distally, labial broader than lingual; mesial narrower than distal; distal more grooved	*Root:* Straight; labially broader than lingually and mesially than distally; former two concave, latter convex; often two roots; sometimes three apex deflected distally	*Root:* Longer and larger than in PM_1; labially is broader than lingually; mesially and distally is equal; single; may be bifid or trifid	*Roots:* Two, mesial and distal; *mesial* inclines to distal at apex; is larger, and broad buccolingually; grooved mesially and distally. *Distal* inclines backward, grooved mesially	*Roots:* Two; anterior broader and shorter than posterior, and deflected backward, and is grooved; distal root straight, narrow, long; deflected backward and grooved mesially	*Roots:* Generally two; short and taper rapidly; often confluent; may be even four or five roots; as a rule roots deflected backward
Calcification	Begins first year post-natum; completed in 10th year	Begins first year post-natum; superficially completed 10th–11th year	Extends from 3rd to 12th or 13th year	Begins about 4th year; superficially completed 11th–12th year	Begins about between 4th–5th year; superficially completed 11th–12th year	Begins 8th month intra-uterine life; superficially completed 9th–10th year	Begins about 5th year post natum; superficially completed 16th–17th year	Begins 8th–9th year; superficially completed by 18th year
Pulp canal	*Pulp cavity:* Outline same as in tooth: flattened labio-lingually; may be bifurcated, with two canals, united at apex	*Pulp chamber* and *root canal:* Much as in I_1; root canal tends to bifurcation	*Pulp cavity* and *root canals:* Resemble those of maxillary teeth, but are more flattened from side to side	*Pulp cavity* and *root canals:* Both follow shape of tooth; canal almost cylindrical and may be bifurcated	*Pulp cavity* and *root canals:* Has two coruna, one labial, one lingual; single canal, flattened from side to side	*Pulp cavity* and *root canals:* Cavity is quadrilateral. Three canals; one in distal root, two in mesial root; all flattened laterally	*Pulp cavity* and *root canals:* Conform closely to shape of tooth	*Pulp cavity* and *root canals:* Vary with the tooth itself
Identification	Place tooth horizontally with apex of root toward observer; longest side (i.e. from angle to apex) is on side to which tooth belongs	Same as in I_1; large mandibular incisor is probably I_2	Place tooth in horizontal position with apex of root toward observer; shorter portion of cutting edge (between cusp and mesial surface) points to side to which tooth belongs	Hold with crown up, and convex "bent" labial surface nearest observer. Rounder portion of crown carrying mesial pit is placed on side to which tooth belongs	Very difficult. Practically impossible to determine, with certainty, to which side it belongs	Hold crown uppermost with 5th cusp away. Pit on buccal surface is on *opposite* side to which tooth belongs. If pit is absent, rounded nature of buccal surface gives a similar clue	Distinguished by square crown and two roots. Hold with crown up, with larger root near observer. Flat internal lingual side or surface points to side to which tooth belongs	Almost impossible to determine to which side it belongs. If it is typical it may be identified much as M_2
Eruption*	Between 6th–7th years	About 7th year and 6th month	About 11th year	Just before 10th year	About 10th year and 6th month	Midway between 6th and 7th years	About 12th year	About 20th year, if at all

* See also the various associated *tables*.

TABLE 5

Anatomical characteristics of the permanent maxillary teeth (right side)

CRITERIA	MEDIAN INCISOR	LATERAL INCISOR	CANINE	FIRST PREMOLAR	SECOND PREMOLAR	FIRST MOLAR	SECOND MOLAR	THIRD MOLAR
Mean measurements	Length from incisive edge to apex, 25 mm.; width, 9 mm. usually very large. Varies: Length, 14–32 mm.; width, 5.75–10 mm. *Black:* Crown, 0.39 in.; root, 0.49 in.; total, 0.88 in.	Extreme length, 23 mm.; extreme width, 6.5 mm.; smaller than I^1. Varies: 18–31.5 mm.; 5.5–7 mm. *Black:* Crown, 0.34 in.; root, 0.51 in.; total, 0.85 in.	Length from apex of root to tip of cusp, 27 mm.; width in coronal region, 8 mm.; quite large. Varies: 8–38 mm.; 5.5–9 mm. *Black:* Crown, 0.37 in.; root, 0.68 in.; total, 1.05 in.	Extreme length, 20 mm.; extreme width, 6.5 mm. Varies: 13–28.5 mm.; 6.5–8 mm. *Black:* Crown, 0.32 in.; root, 0.48 in.; total, 0.80 in.	Extreme length, 22 mm.; extreme width, 5 mm. Varies: 16–28 mm.; 5–8 mm. *Black:* Crown, 0.30 in.; root, 0.54 in.; total, 0.84 in.	Apex of palatine root to crown, 22 mm.; anterior buccal root, 21 mm.; posterior buccal root, 19 mm.; anterior buccal root varies 10–29 mm. in length; across crown varies 4.5–11 mm. mesio-distally *Black:* Crown, 0.30 in.; root, 0.51 in.; total, 0.81 in.	Apex of palatine root to crown, 22 mm.; width across mesial surface, 11 mm. Varies: 24–29 mm.; 10–12 mm. *Black:* Crown, 0.28 in.; root, 0.51 in.; total, 0.79 in.	Apex of anterior buccal root to crown, 20 mm.; width of mesial surface, 11 mm. Varies: May be small as 10 mm long and 4.5 wide in both directions *Black:* Crown, 0.24 in.; root, 0.44 in. total, 0.68 in.
Coronal surfaces and angles	*Labial:* 9 x 12.5 mm.; triangular, base at incisive edge; convex side to side and above down; smooth and shiny *Lingual:* Triangular; concave side to side and above down *Mesial:* Smaller than distal; convex in both directions; triangular, apex below *Distal:* Triangular, as in mesial *Mesial angle:* Right angle *Distal angle:* Obtuse angle	*Labial:* 6.5 x 10 mm.; more convex both ways than I^1, and upper border less rounded; surface smoother; may have two tubercles until 11th year *Lingual:* More extensive vertically than labial; concavities more marked; cingulum present in gingival region *Mesial* and *distal* about the same; former flat, latter more rounded *Mesial angle:* Obtuse *Distal angle:* More so. Longitudinal axis of the	*Labial:* Very convex; divided unequally by longitudinal ridge of enamel; upper border on level with root surface *Lingual:* More triangular than labial; concave side to side and above down; divided by ridge as in labial *Mesial:* Flattened backwards and side to side; less triangular; crown, neck, and root in almost even plane *Distal:* At junction of distal part of lower border, crown is much thicker	*Crown:* Cuboidal in shape, lingual portion being smallest *Labial:* Convex side to side and above down; may have ridge and grooves as in canine, but not vertically; is diamond-shaped *Lingual:* Convex in both directions; no grooves or ridges *Mesial:* Quadrilateral; concave both directions; tend to vertical groove *Distal:* Same as mesial, but more convex *Morsal:* Trapezoidal; greatest	*Labial:* Convex in both directions, less than PM^1; widest across middle; upper border less curved than PM^1 and cusps more equal *Lingual:* Marked, and borders and angles rounded *Mesial* and *distal:* not parallel; slope upward toward root *Morsal:* Resembles PM^1 except here central sulcus less deep	*Crown:* Large and conical; buccal and lingual surfaces rounder than mesial and distal *Buccal:* Convex in both directions; twice size of PM^2; quadrilateral; grooved midway between anterior and posterior borders from above down; narrowest at neck *Palatine:* More irregular and rounded; narrowest at neck; convex in both directions; grooved as in buccal, but anterior half larger	*Crown:* Smaller, more triangular than M^1; more rounded *Buccal:* Like M^1, but shelves toward distal part; grooves not so marked *Palatine:* Very convex; not so grooved as M^1; distal portion may be smaller *Mesial* and *distal:* more convex than M^1; mesial broader than distal, which is more convex *Morsal:* Protocone largest; two deep anterior and posterior fossæ; metacone and protocone joined	*Buccal:* Same as M^1 and M^2, but shorter and more convex; may have vertical groove on lower border *Palatine:* Narrow antero-posteriorly convex; not grooved *Mesial:* Flat and broad; slopes upward from roots *Distal:* Very rounded, convex and short; all angles round *Morsal:* Hypocone small and may be absent; oblique ridge as in M^2 absent where tooth is tricuspidate

TABLE 5—*Continued*•

Coronal surfaces and angles—Con.		tooth is in a straight line	*Angles:* Obtuse, especially distal; very blunt and rounded	diameter labio-lingually; angles very rounded; outermost cusp most prominent of the four crests; two main cusps ("bicuspid")		*Mesial:* Rhomboidal; slightly convex; may be slightly depressed *Distal:* Quadrilateral; grooved as in buccal *Morsal:* Quadrilateral, cusp at each angle; protocone largest, paracone next, then metacone and hypocone; 5th cusp may appear near protocone	by oblique ridge	
Neck	Formed by convergence of four surfaces and consists of their upper borders; not in same plane; dips mesially and distally at spot midway between labial and lingual surfaces	V-shaped outline of neck not so greatly marked as in I^1; cingulum varies greatly	Neck ill-defined; in some cases may be noted only through difference in enamel and cementum	Nearly horizontal; dips on mesial and distal surfaces	Practically indistinguishable except for free margin of enamal; plane of cervical region is horizontal	Horizontal section is rhomboidal, larger on palatine side than buccal; amelo-cementum junction indistinct	Irregular in outline and circumference; marked by annular depression	Oblong mesio-distally; marking better distally than mesially
Roots	Cone-shaped and nearly cylindrical; convex mesially; curved distally; tapers to extremity	Cone-shaped, but flattened from side to side; may be bifurcated; mesial and distal aspects broader than labial and lingual; apex generally deflected distally	Laterally flattened cone; very long; mesially and distally is 8 mm.; labial 5 mm.; lingual 4 mm.; apical region often deflected	Flattened side to side; mesio-distal grooving may cause two roots; may be 3 roots, 2 labial, 1 lingual (an anomaly); tendency for roots to diverge at apical regions	Longer, smaller, flatter, than PM^1, may be bifurcated, with 2 pulp canals, 1 buccal, 1 lingual; straight; anterior groove less than distal	Palatine, and anterior and posterior buccal; posterior shorter and flatter than anterior; anterior tends to groove and backward curve; palatine most divergent; cylindrical and deflected at apex; buccals may fuse, and occasionally all three	Three, not so divergent as M^1; generally curved distally; all may fuse, grooves showing line of diffusion; palatine and anterior buccal roots often fuse, rarely palatine and posterior buccal	Same as M^1 and M^2; roots may converge, or may be 4–6 roots; very variable; roots smaller and more slender palatine smallest; if tri-cuspidate, outer two roots tend to be confluent
Calcification	Begins 1st year post-natum; completed by 10th–11th year	Begins in first year post-natum; completed by 10th–11th year	Begins 3rd year; superficially completed by 12th–13th year	Begins 4th year; superficially completed 11th–12th year	Begins 5th year; superficially completed by 11th–12th year	Starts about 8th month of intra-uterine life; hard parts superficially completed by 9th–10th year	Begins about 5th year; completed 16th–18th year	Begins about 9th year; superficially completed 18th–20th year

• Concluded on the succeeding page.

TABLE 5—*Continued*

ANATOMICAL CHARACTERISTICS	MEDIAN INCISOR	LATERAL INCISOR	CANINE	FIRST PREMOLAR	SECOND PREMOLAR	FIRST MOLAR	SECOND MOLAR	THIRD MOLAR
Pulp canal	*Pulp canal:* In labio-lingual direction, conforms to shape of tooth; mesio-distally is broader at lower edge; transversely is cylindrical	*Pulp canal:* Relative to tooth is greater than in I^1, hence is but little smaller	*Pulp canal:* Shaped like tooth; transversely outer half broader than lingual section	*Pulp chamber:* Imitates outlines of crown; greatest diameter labio-lingual; two *pulp canals*, pulp chamber being bifurcated near neck of tooth	*Pulp chamber:* Outline same as tooth; root canal usually single and flattened from side to side; if there are two *root canals*, they may terminate in one apical foramen	*Pulp cavity:* General shape of tooth; buccal canals flattened; palatine cylindrical	*Pulp cavity* and *root canals:* Pulp cavity shaped like tooth, but more oblong from buccal to palatine sides; canals shorter and flatter laterally than M^1	*Pulp cavity* and *root canals:* Outline of pulp cavity varies; generally triangular, outer side being shortest; root canals very small and close together
Identification	Hold in horizontal position between forefinger (left) and thumb, with convex surface of crown upward and root away; sharper angle of cutting edge points to side to which it belongs	Much as in I^1; sharper angle cutting edge points to side to which it belongs	Same as for I^1 and of I^2; considering location of prominence on distal surface, one can tell to which side it belongs	Hold tooth with crown toward observer with large external cusp pointing in same direction. Deeper grooving of root, on mesial or canine side, points to side to which it belongs	Difficult; if small, with rounded margin on crown, short central coronal sulcus, is PM^2. Practically impossible to say right or left	Hold palatine root in left hand between thumb and index finger with crown upward. End of oblique ridge of enamel nearest holder points to side to which it belongs	Observe rounded edge of crown over palatine root; hold and observe as in M^1	Size, slenderness of roots and absence of other features of M^1, and M^2. If tricuspid is M^3. Hold as in M^1, then flattened mesial surface of crown points to side to which it belongs
Eruption†	About 7th year and 9th month	About 9th year and 3rd month	About 10th year and 6th month	About 9 years, to 9 years and 6 months	About 10th year and 3rd month	About 6th year to 6th year and 6th month	About 11th year and 9th month	About 17th–20th year; may delay to middle age, or not at all

† See also the various associated *tables*.

4. Occlusion of the teeth

The occlusion of the teeth is a problem which at present is being forced to the fore by Hellman.[31] Roughly speaking, we mean by occlusion the articulation of the maxillary and mandibular teeth.[32] The whole aspect of occlusion, and especially malocclusion, has been ably dealt with by Angle.[33] In fact, the whole dispute now is whether Angle's observations hold true. Let us first observe what is termed "normal" occlusion by Angle:[34]

TABLE 6

Average measurements of the upper and lower deciduous teeth

TOOTH	MILLIMETERS AND TENTHS OF MILLIMETERS						
	Length over all	Length of crown	Length of root	Mesio-distal diameter of crown	Mesio-distal diameter of neck	Labio-lingual diameter of crown	Labio-lingual diameter of neck
Upper teeth							
Central incisor.....	16.0	6.0	10.0	6.5	4.5	5.0	4.0
Lateral incisor.....	15.8	5.6	11.4	5.1	3.7	4.8	3.7
Cuspid.....	19.0	6.5	13.5	7.0	5.1	7.0	5.5
First molar.....	15.2	5.1	10.0	7.3	5.2	8.5	6.9
Second molar.....	17.5	5.7	11.7	8.2	6.4	10.0	8.3
Lower teeth							
Central incisor.....	14.0	5.0	9.0	4.2	3.0	4.0	3.5
Lateral incisor.....	15.0	5.2	10.0	4.1	3.0	4.0	3.5
Cuspid.....	17.0	6.0	11.5	5.0	3.7	4.8	4.0
First molar.....	15.8	6.0	9.8	7.7	6.5	7.0	5.3
Second molar.....	18.8	5.5	11.3	9.9	7.2	8.7	6.4

"In their normal relationships the external curve of the lower arch is slightly smaller than that of the upper, so that in occlusion the labial and buccal surfaces of the teeth of the upper jaw slightly overhang those of the lower. The paracone of M^1 is received in the buccal groove of M_1. The teeth posterior to the first molars engage with their antagonists in a

[31] Hellman, 25, 26, 27.

[32] See Hellman, 25C, pp. 698–702, for modern definitions of occlusion and malocclusion.

[33] Angle, 11.

[34] Angle, 11; pp. 9–12. Cf. Hopewell-Smith, 28; pp. 233–41; Gregory, 22; p. 248; Wiedersheim, 49; pp. 319–20.

TABLE 7

Date of the eruption of the teeth

ORDER OF THE ERUPTION OF THE TEETH	QUAIN	ZUCKERANDL	MAGITOT	DEBIERRE AND PRAVOZ	JAMES AND PITTS
Deciduous dentition					
First mand. incisor	7th–9th month	6th–8th month	7th month	7th–8th month	
First max. incisor				10th month	
Second mand. incisor	Some months later	8th–12th month	10th month	12–14th month	
Second max. incisor			16th month	15th month	
First mand. molar	4 or 5 months later	12th–16th month	20th month	15th–18th month	
First max. molar			24th month	18th–20th month	
Second mand. molar		20th–30th month	26th month	24th month	
Second max. molar			28th month		
Mand. canine	About 24th month	15th–20th month	30th month	24th month	
Max. canine			30th–33rd month		
Permanent dentition					YEAR / MONTH
First mand. molar	6th year	6th–7th year	5th–6th year		6 / 6
First max. molar					6 / 6
First mand. incisor	7th year	7th–8th year	7th year		6 / 6
First max. incisor					7 / 9
Second mand. incisor	8th year	8th–9th year	8th year, 6th month		7 / 6
Second max. incisor					9 / 3
First mand. pre-molar	9th year	9th–11th year	9th–12th year		9 / 9
First max. pre-molar					9 / 3
Second mand. pre-molar	10th year	11th–13th year	11th year		10 / 6
Second max. pre-molar					10 / 3
Mand. canine	11th–12th year	11th–13th year	11th–12th year		10 / 6
Max. canine					11 / 9
Second molars	12th–13th year	13th–15th year	12th–13th year		11 / 9
Third molars	17th–25th year	17th–40th year	19th–25th year		— / —

precisely similar way; those anterior interlock with one another, in the interspaces until the incisors are reached; of these the upper usually overhang the lower about one-third the length of their crowns, though the length of overbite varies.

"The I^1 being broader than I_1, it necessarily extends beyond it distally, overlapping in addition about one-half of I_2; the I^2 occludes with the remaining portion of this tooth and with the mesial incline of C_1; the mesial

TABLE 8

Average measurements of the upper and lower permanent teeth

TOOTH	MILLIMETERS AND TENTHS OF MILLIMETERS						
	Length over all	Length of crown	Length of root	Mesio-distal diameter of crown	Mesio-distal diameter of neck	Labio- or bucco-lingual diameter	Curvature of gingival line
Upper teeth							
Central incisor.....	22.5	10.0	12.0	9.0	6.3	7.0	3.0
Lateral incisor.....	22.0	8.8	13.0	6.4	4.4	6.0	2.8
Cuspid.....	26.5	9.5	17.3	7.6	5.2	8.0	2.5
First bicuspid.....	20.6	8.2	12.4	7.2	4.9	9.1	1.1
Second bicuspid.....	21.5	7.5	14.0	6.8	5.3	8.8	0.8
First molar.....	20.8	7.7	13.2	10.7	7.5	11.8	2.2
Second molar.....	20.0	7.2	13.0	9.2	6.7	11.5	1.6
Third molar.....	17.1	6.3	11.4	8.6	6.1	10.6	0.7
Lower teeth							
Central incisor.....	20.7	8.8	11.8	5.4	3.5	6.0	2.5
Lateral incisor.....	21.1	9.6	12.7	5.9	3.8	6.4	2.5
Cuspid.....	25.6	10.3	15.3	6.9	5.2	7.9	2.9
First bicuspid.....	21.6	7.8	14.0	6.9	4.7	7.7	0.8
Second bicuspid.....	22.3	7.9	14.4	7.1	4.8	8.0	0.6
First molar.....	21.0	7.7	13.2	11.2	8.5	10.3	1.1
Second molar.....	19.8	6.9	12.9	10.7	8.1	10.1	0.2
Third molar.....	18.5	6.7	11.8	10.7	8.3	9.8	0.2

incline of C^1 occludes with the distal incline of C_1; the latter occluding with the mesial incline of the protoconid of PM_1. In the same order the series of buccal cusps of the premolars occlude—the mesial incline of each upper occluding with the distal incline of the corresponding lower tooth.

"The distal incline of PM^2 occludes with the mesial incline of the protoconid of the PM_1. The mesial incline of the protocone of the PM^1 occludes with the distal incline of the protoconid of PM_1; the distal incline

of the protocone of PM^1 occludes with the mesial incline of the protoconid of PM_1; the mesial incline of the metacone of PM^1 occludes with the distal incline of the hypoconid of M_1, and the distal incline of the metacone of PM^1 occludes with the mesial incline of the protoconid of M_2. The same order is continued with the buccal cusps of the second and third molars, the distal incline of the metacone of M^3 having no occlusion.

"It[35] will thus be seen that each of the teeth of both jaws has two antagonists or supports in the opposite jaw except I_1 and M^3.

"As the inclined planes match and harmonize most perfectly in the bucco-occlusal relations of the teeth, so there is a similar arrangement in their linguo-occlusal relations, except that the lingual cusps of the lower buccal teeth project beyond those of the upper into the oral space.

"Likewise in the transverse arrangement, the buccal cusps of the lower molars and premolars rest between the buccal and lingual cusps of the uppers, and the lingual cusps of the upper molars and premolars rest between the buccal and lingual cusps of the lowers."[36]

Angle has here outlined the ideal occlusion—too ideal in fact. It would perhaps not be too great an exaggeration to say that as various people's finger-prints differ, so do their teeth. Maybe there is a closer uniformity in the occlusal relations of the teeth, but I doubt it greatly. Says Gregory:[37] "The low-crowned teeth of man, with rotary and oblique movements of the mandibles, afford opportunity for considerable individual differences." This insistency as regards the ideal "normal" occlusion has led Angle into another trap, viz., he is inclined to regard even minor variations as belonging to a given type or "class" of occlusion. This has aroused a storm of criticism. But before we can discuss this phase, we must see what he has to say on malocclusion.

First, his nomenclature:[38] "A tooth outside the line[39] of occlusion may be said to be in *buccal* or *labial occlusion;* when inside this line, in *lingual occlusion;* if farther forward, or mesial, than normal, in

[35] "In modern man the interlocking alternating arrangement is usually more or less replaced by a condition in which each lower molar articulates with only one upper molar" (?). Gregory, 22; p. 254.

[36] In quoting Angle I have substituted "paracone," etc., for "antero-external," etc.

[37] Gregory, 23; p. 474.

[38] Angle, 11; p. 24.

[39] The line of occlusion is "the line with which, in form and position according to type the teeth must be in harmony if in normal occlusion." Angle, 11; p. 22.

mesial occlusion; if in the opposite direction in *distal occlusion;* if turned on its axis it would be in *torso-occlusion.* Teeth not sufficiently elevated in their sockets would be in *infra-occlusion,* and those that occupy position of too great elevation, in *supra-occlusion.*

Angle's "Classes"[40] are based on "the mesio-distal relation of the teeth, dental arches and jaws, which depend upon the position mesio-distally assumed by the first permanent molars upon their erupting and locking." His classes are as follows:[41]

CLASS I. Arches in normal mesio-distal relations.[42]

CLASS II. Lower arch distal to normal in its relation to the upper arch.

DIVISION 1. Bilaterally distal, protruding upper incisors. Primarily, at least, associated with mouth-breathing.

Subdivision. Unilaterally distal, protruding upper incisors. Primarily, at least, associated with mouth-breathing.

DIVISION 2. Bilaterally distal, retruding upper incisors. Normal breathers.

Subdivision. Unilaterally distal, retruding upper incisors. Normal breathers.

CLASS III. Lower arch mesial to normal in its relation to the upper arch.

DIVISION. Bilaterally mesial.

Subdivision. Unilaterally mesial.

As has been indicated, Hellman is the leader in the fight against the rigidity demanded by Angle's doctrine. Gregory[43] substantiates this when he says: "Hellman has shown that the classic concept of normal occlusion is far too rigid and restricted, since it has left out of account the wide range of variability in the details of occlusion." Hellman[44] ably presents the relation of the process of dentition to occlusion when he observes as follows:

[40] Angle, 11; p. 35.
[41] Angle, 11; pp. 57–8.
[42] Arches normal; anterior teeth may mal-occlude without disturbing the arch.
[43] Gregory, 23; p. 474.
[44] Hellman, 27A.

The process of dentition is a physiologic manifestation, and as such it has to be established on a basis of variation.

The variation of the process of dentition is primarily associated with differences constantly manifested in the upper and lower jaws, in the different sexes, in different groups of the same sex, and also in different races.

Differences in the eruption and shedding of teeth must be distinguished on the basis of a norm established on the evidence of dentitions in normal occlusion.

By having such a norm, a guide is obtained for deciding accelerations and retardations, "premature" or "too long retention" of deciduous teeth, and "tardy" eruption of permanent ones.

In the digression from the normal in the process of dentition, differences in age, differences in length of period, and differences in order of succession in the eruption and shedding of teeth must be distinguished.

These differences are intimately related with the nature of overbite of the incisors, with differences in the frequency of malocclusion, and with the "class" of malocclusion.

Differences in overbite are associated with accelerations in the shedding of the deciduous and in the eruption of the permanent incisors. The excessive overbite may be exaggerated by the retardation in the premolar-molar series.

A higher percentage of malocclusal manifestation is associated with the differences noted (above), by the increase in the length of the period, and also by the modification in the order of succession with which the teeth are lost or erupted.

The combination of all these factors also affects the percentage of Class II malocclusal manifestations.

Not only has Angle been far too strict in defining malocclusion, but he has advanced mouth-breathing as the main, if not virtually the sole, cause of malocclusion. In combating this aspect of the problem Gregory[45] suggests that malocclusion results from a deviation from normal in the size and the time relation of the replacement between the deciduous teeth and their successors and neighbors; while Waugh[46]

[45] Gregory, 23; p. 471.
[46] Waugh, 36; p. xxxiii.

advances, as causes, habits of finger-sucking, etc., adenoid vegetations and abnormal tonsillar conditions, and again the replacement of deciduous teeth by the permanent teeth.

Hellman,[47] after testing Angle's Class II, concludes as follows:

1. Mouth-breathing is not especially concerned in the production of Class II any more than it has influence to produce Class I.
2. The sucking habit has a positive though not exclusive relationship to Class II, Division 1.
3. Artificial feeding[48] stands in direct relation to a higher susceptibility to pathologic conditions.
4. Pathologic conditions have an exaggerating or activating influence upon retardation and acceleration in association with growth.
5. Retardations and accelerations associated with growth influence the formation and completion of the masticatory apparatus as they do everything else that depends upon growth and development for its perfection. And, therefore, they also have an influence in the retarded development and diminutive size of the mandible with distal occlusion in Class II, Division 1, and the forward drifting of the maxillary lateral halves with mesial occlusion of the maxillary teeth in Class II, Division 2.

Hellman's conclusions, above, as to artificial feeding (i.e., bottle-feeding as opposed to breast-feeding) have been tested by the writer with a group of Melanesian skulls at the Field Museum. The assumption is that, should these skulls reveal little or no malocclusion, we must admit artificial food as a prime cause of malocclusion. These Melanesian skulls presumably represent individuals who have, as infants, been raised on mother's milk, for the period of nursing among these people, and primitive people in general, is about three years.[49] On the other hand, should much evidence of malocclusion be found in these breast-fed cases, then obviously Hellman's bottle-

[47] Hellman, 26; p. 20.

[48] This is supported by Howe, 32; p. 453. Hellman, 25A, p. 192, says: "Of a thousand children examined who had malocclusion of the teeth, 80 per cent were found to have been bottle-fed in infancy."

[49] McClendon, 35; p. 280.

feeding must be subordinate. The conclusions are presented in the Appendix.

To return to the problem of nutrition, for this is what bottle- or breast-feeding involves. A new school of dentists has arisen: they believe in the adage that "an ounce of prevention is better than a pound of cure." Angle was content to correct after; they correct before, i.e., prevent. The work is still in its infancy. Gies, in 1919,[50] deplored the "deficiency in our knowledge of the teeth and nutrition." Hellman, Howe, Jackson, and Spier are the leaders in this field. Howe[51] has produced decalcified areas in the bones of the head and in the teeth with a deficient diet, and has effected reca'cification with an adequate diet. He has also produced senility and alveolar absorption through malnutrition. He notes further work along this line as follows:

McCollum and Pitz, and Cohen and Mende!, have, in guinea pigs, caused loosening of the teeth and bleeding or congested gums, associated with a vitamine-deficient diet.

Mellanby has produced irregular teeth in pups by rachitic feeding.

Zilva and Wells have reported degenerate changes in teeth and pulps of guinea pigs fed on a scorbutic diet. This represents but a small, though vastly important, step in the direction toward a thorough knowledge of the factors governing the growth of teeth, both pre- and post-natal. It also[52] points toward a much broader classification of occlusion and malocclusion.

There is another very important phase of the problem of nutrition, viz., the acceleration or retardation of the eruption of the teeth due to nutritive conditions. Sullivan,[53] Boas,[54] Spier,[55] and Hellman,[56] are the pioneers in this field. They have discovered some startling correlations between the state of the diet, i.e., malnutrition, and the age at which teeth have erupted. To quote Sullivan: "Within a group an individual who is more advanced in physical development will manifest this in the earlier eruption of the teeth as well as by

[50] Gies, 30; pp. 31–2.
[51] Howe, 34; p. 11.
[52] Jackson, 29; pp. 156–62.
[53] Sullivan, 45D.
[54] Boas, 12A.
[55] Spier, 45C.
[56] Hellman, 25A.

rapidly increasing in stature and weight. Yet when groups are compared with each other this does not hold. Extreme poverty and other adverse living conditions seem to hasten the date of the eruption of the teeth." Sullivan studied the dentition of all the nine and twelve-year old Mexican boys and girls in the Tucson Public School system, and reported the number of permanent teeth erupted as follows:

	Per cent		*Per cent*
Nine-year girls	13.5	Twelve-year girls	25.3
Nine-year boys	13.3	Twelve-year boys	23.7

Boas worked with Porto Rican school children and concluded that the eruption of the permanent teeth in Porto Rican boys was about a year in advance of Boston boys. This he said was due to: (1) nutritive differences; (2) climatic variations; (3) pathological conditions; (4) "other causes at work that bring about an acceleration of dental development under unfavorable social conditions." His conclusions, together with those of Dr. Hellman on the New York poor, are presented in *table 9* (page 32).

Spier, who worked-over Boas' material from Porto Rico, studied the relation of stature and dentition, and presents the following illuminating conclusions:

"At the beginning of the period of rapid increase in the rate of growth, the accelerated individuals must be growing at a higher rate than the retarded individuals of the same chronological age, but who have not yet entered into the period of rapid growth. Conversely, at the end of the period of rapid growth, the accelerated individuals must grow at a slower rate than the retarded. Consequently, at the beginning of the period, accelerated individuals must vary more than retarded individuals from the average of their age and less at the end of the same period. Below are compared the variabilities of the retarded and accelerated groups of each age.

AGE	RETARDED GROUP	ACCELERATED GROUP	DIFFERENCE
7	52	56	+4
8	49	56	+7
9	41	45	+4
10	61	68	+7
11	61	54	−7
12	71	74	+3
13	90	76	−14

"While the results are not marked, the accelerated group varies more than the retarded group at the beginning of the period of rapid increase of the rate of growth, but less at the end of the same period. The converse holds true for the retarded group. From another point of view the increased variabilities in stature for both accelerated and retarded groups may be an expression of a different rate of development from that of dentition. If this is so, the greater the degree of acceleration or retardation of

TABLE 9

Percentage of permanent teeth present in the upper jaws in boys aged six to fifteen years

AGE	CANINES					FIRST BICUSPIDS				SECOND BICUSPIDS			
	Porto Rico	Boston	N. Y. poor	N. Y. well-to-do	Saxony	Porto Rico	Boston	N. Y. poor	N. Y. well-to-do	Porto Rico	Boston	N. Y. poor	N. Y. well-to-do
6	—	—	—	—	—	—	2	—	—	—	—	10	2
7	—	3	3	—	1	4	2	14	2	8	11	8	—
8	20	—	1	—	—	27	21	19	7	28	19	38	2
9	30	—	8	—	2	56	39	46	11	32	32	47	20
10	41	33	23	15	11	65	63	62	35	56	54	61	36
11	62	61	42	45	32	83	76	77	66	79	55	85	63
12	77	85	77	78	65	94	80	94	88	87	67	88	85
13	89	91	100	85	82	95	87	99	97	99	77	97	88
14	97	100	91	100	91	100	96	97	100	100	—	90	83
15	100	100	86	100	100	100	100	96	100	97	—	?	100

dental development, the greater will be the variations in stature. There is a marked functional relation between stature and stage of dental development."

IV. ORIGIN OF THE HUMAN TOOTH-FORM

An examination of palæontological material, or even a glance at the teeth of a reptilian form, e.g., an alligator, will suffice to show that the tooth-form has not always been like that found in man in particular, and mammals in general. In reptiles and very early forms the teeth are not cusped, but are mere conical growths, so that the term "reptilian cone" readily conveys the idea of the primitive tooth as opposed to the modern type exemplified in man.

1. Reason for the evolution of mammalian molar types

Many and diverse theories have arisen to explain the evolution of the modern tooth-form. That the mammalian molar has evolved, and from a primitive or antecedent reptilian form, is not for a moment disputed, but as to the reason for its evolution there is important disagreement. Broadly speaking, there are two major explanations for these phenomena: (a) one holding that the whole process was purely mechanical—that because of certain stresses rising in the mastication or procuring of food, the organism responded with a mechanism capable of performing the required task; (b) the other maintaining that the whole process is that of simple accidental variation and selection. It is at once apparent that the first explanation involves the Lamarckian principle of "use and disuse," or "kinetogenesis," which has been defined by Cope[57] as "the doctrine or hypothesis that animal structures have been produced directly or indirectly by animal movements." Before we can estimate the validity of the application of Lamarck's doctrine to the problem of the evolution of the mammalian molar, we must first observe those theories that use kinetogenesis as a basis, viz., the theories of Cope and Ryder, as specifically set forth in Ryder's paper on "the mechanical genesis of tooth forms." It is first imperative, however, that we notice and define certain terms which will be frequently used.

The words "homology" and "analogy" are often referred to in discussing the origin of the teeth. We speak, in general, of lateral homology, meaning the structural identity of the organs on both sides of the body. Dental homology comes under this class: "It means the correspondence in relative structure, position, proportion, value, and development of the teeth, but not in shape, size, or function."[58] Thus, teeth are said to be homologous with dermal spines, as for instance the placoid spines or scales of the dog-fish. Dental analogy, on the other hand, involves "different organs which perform similar functions."[59] For example, the denticulated lower incisors of *Galeopithecus volans* and the epithelial papillæ of the tongue of the

[57] Lull, 38D; p. 179.
[58] Hopewell-Smith, 28; pp. 133–4. Cf. Thompson, 46A; pp. 23–4.
[59] Hopewell-Smith, 28; pp. 133–4.

cat are two entirely different things, yet both are for combing the fur. They are analogous through function.

Ryder[60] has adopted Cope's[61] nomenclature for the four principal types of teeth which, speaking phylogenetically, are these:

1. *Haplodont:* crown undivided or simple; may be (a) low, obtuse· (b) elevated, acute; (c) truncated.
2. *Ptychodont:* crown folded on sides, folds frequently crossing crown, (a) sides, only, folded; (b) summit of crown also folded.
3. *Bunodont:* crown supporting tubercles; (a) tubercles few, opposite; (b) tubercles few, alternate; (c) tubercles numerous; irregular.
4. *Lophodont:* summit of crown thrown into folds of transverse or longitudinal direction.

With reference to the upper and lower molars we may recognize two types:

a. *Isognathous:* molars of both jaws identical.
b. *Anisognathous:* where mandibular bone thinner; superior molars wider than inferior.

Turning now to the theory of kinetogenesis, (1) in carnivora and omnivora the jaws simply opened and closed in mastication, there being no lateral movement of the mandible. Here we have the earliest and most constant type of tooth, i.e., the haplodont. Again, here the distances between the upper and lower series of molars were approximately alike, i.e., when the jaws were closed the buccal cusps of the upper series were brought directly down on the lower series and not over them. This is *isognathism.*

(2) In the herbivora the jaws opened and closed in mastication with much lateral mandibular movement. The tubercular structure of the teeth was hence modified to give a crescentic, long-rooted, selenodont type of tooth. The distance between the upper series of molars was greater than between the lower series. Hence the buccal cusps of the upper series closed over the buccal cusps of the lower. This is *anisognathism.*

(3) In some rodentia and proboscidea the mandibles moved back-

[60] Ryder, 43; pp. 45–80.
[61] Cope, 18; pp. 72–3.

ward and forward, or an antero-posterior movement, which may be denoted a "reciprocating movement." This gives a *ptychodont* tuberculation, with three tubercles forming transverse ridges. There also results frequently obsolete, or greatly flattened transverse lamellae, composed of elongated and united tubercles soldered together by a thick cementum layer (Elephas). Isognathism is present here.

(4) In a subdivision including part of the rodentia and proboscidea

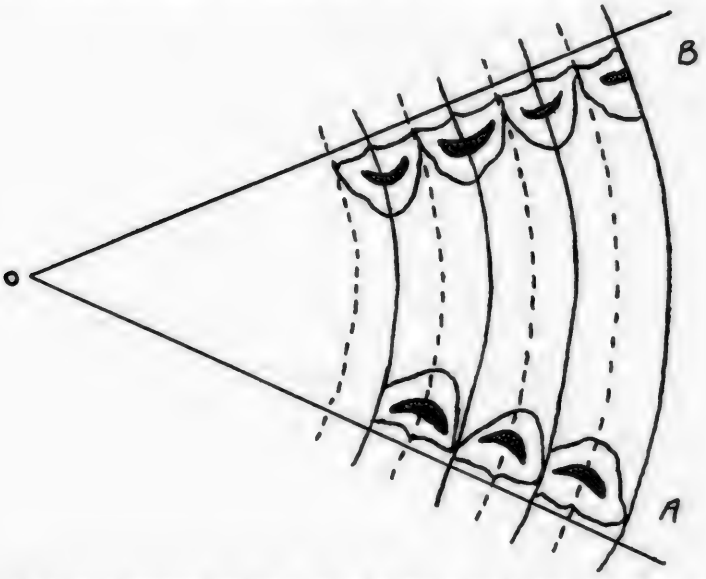

FIG. 2. DIAGRAM SHOWING THE IDEAL MODE IN WHICH THE LOWER MOLAR SERIES, *A*, SWEEPS OVER THE UPPER SERIES, *B*, THE MOVEMENT BEING CONSTANTLY REGULATED FROM THE MANDIBULAR ARTICULATION, OR ODONTOMORPHIC CENTER, *O*.

(Ryder, 43; p. 72)

(mastodon), the movement of the mandible was reciprocating plus lateral. The result is a ptychodont dentition: the enamel is fluted and folded upon itself longitudinally and laterally. Anisognathism is present here, as a rule.

The whole theory is greatly clarified if we briefly observe the mechanics of the movement of the mandible. The mandible may be likened to a bar, fixed at one end, and free at the other. It may pos-

sibly make the following movements, corresponding to Ryder's four stages (*fig. 2*):

A. Vibratory movement in a vertical plane.
B. Vibratory movement in vertical and horizontal planes.
C. Vibration in approximately a horizontal plane, neither lateral nor vertical, but antero-posterior, parallel to the medial axis.
D. Fourth movement combining, to a great extent, the second and third.

The kinetogenetic hypothesis has received the support of a great number of writers. It accounts admirably for the development and heterogeneity of the more advanced forms. To quote Osborn:[62]

"Two hypotheses may be advanced to explain the evolution of the tritubercular type. The first is that the type has been acquired by the selection of accidental variations in the production of new cusps and modelling of old ones. The second is, that the interaction of the upper and lower molars in the movements of the jaws has resulted in local increase at certain points, resulting first in new cusps, then in a change of position and form of the cusps. Both hypotheses are open to numerous objections and are by no means mutually exclusive. . . . . The balance of evidence in tritubercular evolution seems to favor the second, or kinetogenesis theory, as apparently witnessed in two laws of cusp development:

1. The primary cusps first appear as cuspules, or minute cones, at the first points of contact between the upper and lower molars in the vertical motions of the jaws.

2. The modelling of the cusps into new forms, and the acquisition of the secondary positions is a concomitant of interference in the horizontal motions of the jaws."

Gregory[63] likewise indorses the idea that mechanical interaction may have caused the differentiation of the several kinds of teeth. Noting that the anterior premolars are less complex than the posterior, he says:

"The adaptive meaning of the simplification of the premolars as we pass forward is as follows: The anterior teeth are further away from the fulcrum, which is the glenoid articulation, and further away from the in-

[62] Osborn, 39; pp. 42–3.
[63] Gregory, 22; pp. 242–3.

sertion areas of the masseter, temporal, and pterygoid muscles. Hence the anterior teeth sweep through a larger arc, that is, have greater velocity than do the molars, which are, on the other hand, in the best position for exerting slow vertical pressure. The premolars are thus intermediate in position and in function between the canine and molars. But a greater velocity, associated with a smaller cross-section and a sharper tip, imparts to the canines a relatively great piercing power. Consequently the anterior teeth retain the original haplodont crown, while in the cheek teeth this crown has become expanded and subdivided."

Duckworth[64] maintains that the differentiation of the incisors "must be ascribed partly to mechanical influences, such as the size and arrangement of the muscles acting on the mandible." Marett Tims[65] believes that the premolar cusps in the cat and hyena "may be due to mechanical agencies," causing "elevation of the ends of the internal cingula." Cope,[66] "with minor exceptions," accepts Ryder's views, while Wortman[67] holds the kinetogenetic hypothesis to be "little short of axiomatic."

The theory of kinetogenesis is open to serious attack on several points:

"First, the apparently illogical and self-contradictory assumption that stimuli of different kinds produce similar results, while stimuli of the same kind may produce different results. Experiment, however, has proved the truth of this apparently paradoxical statement, for the irritation of bone will produce either bone deposits or bone absorption according to the degree of irritation. Thus moderate stimulus, such as the pressure and stretching of certain parts, may stimulate growth. Continued heavy pressure, on the other hand, causes bone absorption at the point of contact.

"A second objection which has been made to kinetogenesis is that if growth-stimulus exists, how can there be a limit to increase, so long as the stimulus of use prevails? This objection is met by the assumption that the stimulus is stress due to disharmony between an organism and its environment, and that kinetogenesis is the result of the effort on the part of the organism to overcome this lack of harmony. When the organism is sufficiently adjusted to meet the requirements of the environment,

[64] Duckworth, 20; p. 252.
[65] Hopewell-Smith, 28; p. 138.
[66] Cope, 19; p. 222.
[67] Wortman, 10; p. 177.

equilibrium is attained, the stress is reduced to the point necessary for the maintenance of the mechanism in working condition, and further growth ceases. In each circumstances, where little or no exertion is necessary, there is not even sufficient stimulus to raise the mechanism to a state of efficiency, and the degeneracy of disuse results.

"Despite Cope's arguments, this is one of the objections to his theory which is most emphasized by its opponents. It will at once be seen that even if the objections above are met, a third will yet remain, that of the acceptance of the Lamarckian factor of the inheritance of acquired or ontogenetic characters, upon which the whole doctrine of kinetogenesis depends for its inclusion among the potent factors of evolution."[68]

2. Method of the evolution of mammalian molar types

The majority of the writers on the problem of the origin of the mammalian molar form have approached it from the methodological angle, i.e., they have asked themselves not why, but how. They see as an end-product the molar of the placental, and recognize that once we are within the placentals we can usually adopt a definite terminology, e.g., Osborn's. But this is aside from the main problem; what they want to know, and what they attempt to explain, is how to get from the reptile to the placental, and thence onward to the higher forms. There are, roughly speaking, two main explanations of this baffling transition from reptilian to mammalian dentition: (*A*) the first maintaining the mammalian molar to be the result of the fusion of two or more reptilian teeth; (*B*) the second holding that the mammalian molar is the product of but one reptilian tooth.

(*A*) The concrescence theory of Röse and Kükenthal, and to some extent of Ameghino,[69] is the foremost of the theories which maintain that the mammalian molar has evolved from several reptilian teeth. This theory holds that the occurrence of multicusped teeth may be explained by the shortening of the jaw and consequent crowding of the teeth leading to the coalescence of several simple conical teeth to form a single tooth with several cusps. Thus it would regard the five-cusped human molars as derived from the coalescence into one tooth of five originally distinct simple conical teeth. This view

[68] Lull, 38D; pp. 187–8.

[69] Tomes, 48A; pp. 333–334. Cf. Osborn, 39; pp. 57–9.

was supported by Virchow, who thought that a case in which the place of a molar had been taken by three peg-shaped denticles with separate roots was an instance of atavism. This coalescence might take place in the length of the jaw, and result in a shortened jaw with a smaller number of more complex teeth, or it might take place laterally, in which case the teeth fused would be of successive series, i.e., of different dentitions. On this latter supposition Kükenthal would regard a molar tooth with its outer and inner cusps as the product of the lateral fusion of one or two temporary teeth with one or two of the permanent series.

The plexodont theory, which Gregory[70] asserts "should be as dead as the Copernican theory," also advances the idea that the mammalian molar is the result of the fusion of several reptilian teeth. It runs somewhat as follows:[71] The oldest form of lower molar, aside from the haplodont reptilian type, is the plexodont. The original form of the plexodont upper or lower molar was supposed to be quadrangular and quadrituberculate. The oldest known form, however, had an anterior and posterior lobe, each with three cusps. This form is ancestral to the tritubercular, triconodont, and protodont stages.

The dimere theory of Bolk[72] is the latest and, in some respects, the most formidable theory in support of the view that the mammalian molar has its origin in more than one reptilian tooth. It is of such comparative recency that an absolute evaluation of it is still almost impossible, though many writers, particularly Adloff, have denounced it in no uncertain terms. In general, palæontological evidence is against it, for reptiles may develop cusps in their molars analogous to mammals, and there is no evidence of fusion in the earliest mammals. Its major tenets are as follows:

1. Hypothesis of triconodonty. It is affirmed that the reptilian tooth from which that of mammals was evolved was not of a haplodont type, but triconodont. The conical tooth of the crocodilia is not a primitive form, but derived secondarily from a tooth com-

[70] Gregory, 23; pp. 461–2.

[71] Osborn, 39; pp. 201–2; Duckworth, 20; pp. 294–5. (Marett Tims accepts concrescence in the molars. Tomes, 48A; p. 334.)

[72] Bolk, 14 and 14A; Tomes, 48A; pp. 346–7.

pressed from side to side, and with a sharp cutting edge. Such a form of tooth is to be found in the embryo of *Crocodilus porosus*, but which neither cuts the gum or is functional. It is also frequently met with in other reptiles, e.g., lizards, as well as in the extinct cynodontia.

2. Hypothesis of dimery. Every mammalian tooth, with certain exceptions, is homologous with two reptilian teeth, the outer series of cusps of the molars and premolars representing one reptilian tooth and termed the *protomere*, the inner series a second tooth and named the *deuteromere*, each longitudinal half of the two forming a single odontomere which is thus monomerous. The existence of the *tuberculum impar*, or tubercle of Carabelli, a minute tubercle occasionally present on the inner face of the internal cusps, Bolk regards as an abortive attempt at tritomerism. The mammalian tooth-germ is thus not the homologue of one reptilian tooth-germ, but of two. The complete tooth-germ of the mammal is really a duplicate organ. The double nature of the tooth-germ is evidenced by the double connection of the enamel-organ with the epithelial lamina from which the teeth are developed, by the two centers of pulp formation. This latter is confirmed by Ahrens, who states that at an early stage of tooth development the layer of ameloblasts is divided into labial and buccal portions by the enamel septum being continuous with the apex of the dental papilla.

3. Hypothesis of concentration. In the development of the reptilian teeth, Bolk regards an individual tooth and its numerous successors as a "tooth family," one tooth generation succeeding another with more or less prolonged intervals. In the mammals the power of producing numerous generations (i.e. polyphyodontism) is much reduced, and the intervals much shortened. As a consequence there is a concentration of the anlage of two reptilian teeth to form one mammalian tooth. Bolk distinguishes between concentration and concrescence.

4. Hypothesis of equivalence. The elements of a mammalian set of teeth are all morphologically and genetically equivalent. The terms mono- and multi-cuspidate possess only a descriptive anatomical value and do not indicate any morphogenetic differences. The differences in shape are solely of a quantitative nature. The anlage of every tooth possesses the potentiality of developing all the cusps

found in the most complicated tooth of the set. "Complication," says Bolk, "is to be regarded as completeness." Simplicity of the tooth is explained by the fact that the anlage of a tooth develops its potentialities in a more or less incomplete manner.

From the foregoing it is clear that, according to Bolk's theory, the fundamental type of a mammalian tooth is sexitubercular, the protomere and deuteromere each representing a triconodont reptilian tooth, the central cone in each being the most pronounced. This has led Bolk to an extremely convenient method of indicating the cusps. A sexicuspidate tooth is indicated by the formula $\frac{1\ P\ 2}{1\ D\ 2}$, the main cone of the protomere and deuteromere being indicated by capital letters, and the anterior and posterior cuspules by small numerals. If the latter should fuse with the former, such a condition is shown by $\frac{P}{D}$, i.e., a bicuspid type of tooth. If the main be subdivided into two, as in the molar teeth of a man and many mammals, this is shown by the formula $\frac{a\ P\ Pp}{a\ D\ Dp}$.

To the above account of the evolution of the mammalian molars and premolars, Bolk regards the teeth of the multitubercula and proboscidea as partial exceptions. Whereas the bulk of the mammalia are dimerous, these animals are polymerous. An elephant's molar represents not merely two generations of a tooth family, but the whole family of at least ten generations, the anterior lamellae representing the oldest generation and the posterior the youngest, the relative positions of the generations as compared with other mammals being due to a rotation of the tooth-germ in the jaw of the fœtal elephant, of which Bolk thinks he has found evidence.[73]

The ordinary types of mammalian incisors and canines are regarded as forms in which the deuteromere is much reduced but is still visible in the thickening to be observed near the cervical border of the lingual surface. The main cusp of these teeth, as is well known, often exhibits a triconodont pattern, interpreted by Bolk as a retention of the primitive triconodont protomere. In this light heterodontism is due to the variable development of the deuteromere. Haplodontism

[73] Tomes, 48 (8 ed.); p. 485.

is a secondary condition, whether occurring in Odontocetæ or in Crocodilia.

(*B*) The foremost theory to maintain that the mammalian molar is the product of but one reptilian tooth is the justly famed Cope-Osborn theory. As in the case of the kinetogenesis theory, we must

TABLE 10

Showing the phylogenetic order as observed by Cope and Osborn, and the ontogenetic order as observed by Röse and Taeker

GEOLOGICAL PERIODS	PHYLOGENETIC ORDER			ONTOGENETIC ORDER			
	Order	Comparative	Human	Primates	Marsupials	Ungulates	Order
Upper molars							
Permian	1	Protocone	Ant. lingual	Paracone	Paracone	Paracone	1
Triassic and Jurassic	2 and 3	Paracone, Metacone	Ant. lateral, Post. lateral	Protocone, Metacone	Protocone, Metacone	Metacone, Protocone	2 and 3
Cretaceous	—	—	—	—	—	—	—
Eocene and Miocene	4	Hypocone	Post. lingual	Hypocone	Hypocone	Hypocone	4
Lower molars							
Permian	1	Protoconid	Ant. lat. degenerated[1]	Protoconid	Protoconid	Protoconid	1
Triassic and Jurassic	2 and 3	Paraconid, Metaconid	Ant. lingual	Metaconid, Hypoconid	Paraconid, Hypoconid	Metaconid, Hypoconid	2 and 3
Jurassic	4	Hypoconid	Post. lateral	Entoconid	Entoconid	Entoconid	4
Cretaceous	5	Entoconid	Post. lingual	Hypoconulid	Metaconid	—	5
Lower Eocene	6	Hypoconulid	Post. mesial	—	—	—	6

[1] This cusp degenerates in the early primates and ungulates. Osborn, 44; p. 742.

first get certain terms clearly in mind before we can proceed to a detailed discussion. Osborn[74] distinguishes the following types of molars:

1. *Haplodont type:* single conical crown; fang single, not distinguished from crown.

1A. *Protodont sub-type:* crown with main cone and lateral accessory cuspules; fang grooved.

[74] Osborn, 39; pp. 39–40.

2. *Triconodont type:* crown elongate, trifid; one central cone and two distinct lateral cones; fang double.

3. *Tritubercular type:* crown triangular with three main cusps; central cone internal in upper molars and external in lower molars.

With reference to the individual molariform we have *bunoid*, meaning a rounded cusp; *lophoid*, meaning a crested cusp; *selenoid*, meaning a crescentic cusp.[75] The following five principles of nomenclature were laid down by Osborn:[75]

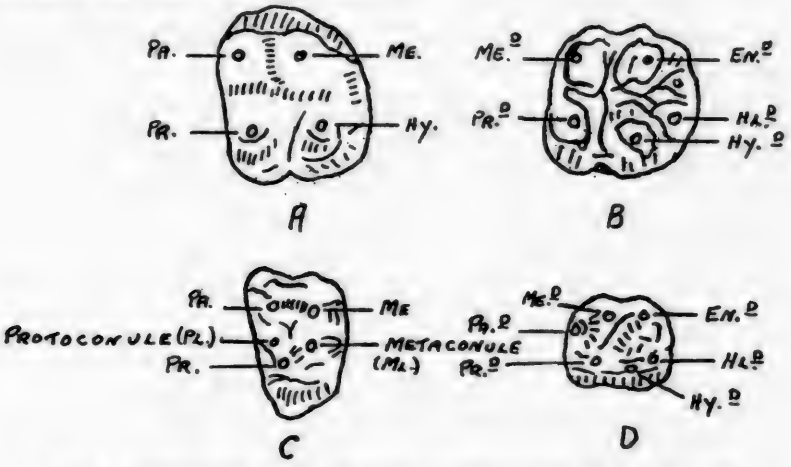

FIG. 3. ILLUSTRATION OF THE OSBORNIAN NOMENCLATURE OF MOLAR CUSPS

A—Second left upper molar of man (Kaffir). *B*—Second left lower molar of man (Australian). *C*—Second left upper molar of *Pelycodus trigonodus*, a Lower Eocene lemuroid. *D*—Second left lower molar of the same. *C* and *D* represent the primitive tritubercular upper molar and the tuberculosectorial lower molar. (Gregory, 22; p. 240.)

(a) The termination *cone* is given to the main, primary, or central cusps, and *conule* to all intermediate cusps.

(b) The termination *style* is proposed for the peripheral cusps arising mainly from the cingulum.[76]

(c) The termination *loph* is applied to the crests.

(d) The seven prefixes are based upon the succession or position of the elements in the primitive evolution of the crown, viz: *proto*, *para*, *meta*, *hypo*, *ento*, *ecto*, *meso*. The prefixes are first applied to

[75] Osborn, 39; pp. 68–70.

[76] See p. 52, this paper.

the cones, then to the styles, according to their proximity to the cones; then to the crests, according to the cones which mainly compose them.

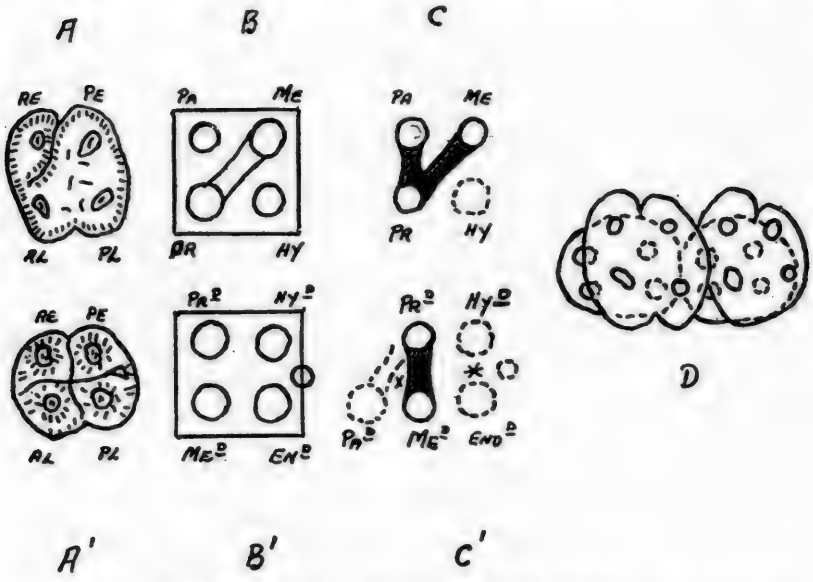

FIG. 4. HUMAN MOLAR TEETH AND THEIR ADJUSTMENT

A—Second upper molar with four cusps. *B*—Same, showing identity of cusps and oblique ridge joining *pr* and *me*. *C*—Same, showing original triangle, to which *HY* has been added in man. A^1—Second molar (lower), with four large cusps and small intermediate cusp posteriorly. B^1—Same, showing identity of the cusps. C^1—Same, showing that cusps *Prd* and *Med* are regarded as remnants of a triangle previously formed there, while the other three cusps (*Hyd*, *Hld*, and *End*) have been added. *D*—Tracings of 2 and 3 upper molars (heavy lines) superimposed upon 2 and 3 lower molars. (From skull of aboriginal Australian.)

Other indications. *AE*—Antero-external cusp. *AI*—Antero-internal cusp. *PE*—Postero-external cusp. *PI*—Postero-internal cusp. *PR*—Protocone. *PA*—Paracone. *ME*—Metacone. *HY*—Hypocone. *PRd*—Protoconid. *PAd*—Paraconid. *MEd*—Metaconid. *HYd*—Hypoconid. *HLd*—Hypoconulid. *ENd*—Entoconid. *HYd*, *HLd*, *ENd*, together constitute the "Talonid."

In C^1 the mark *x* shows where the *HY* of the upper tooth should fall when the teeth close. The mark * shows where the *PR* of the upper tooth should fall in the same conditions. (Duckworth, 20; p. 289.)

(e) Homologous and analogous elements in the upper and lower jaws are given similar terms, but distinguished arbitrarily by the terminal *id*, applying to the lower jaw.

Fig. 3 shows the Osbornian nomenclature of molar cusps. In brief, the Cope-Osborn theory holds that the molars of all the Primates have been derived ultimately from simple trigonal upper molars and tuberculosectorial lower molars. Further, that the tritubercular molars had been derived from a triconodont type with three cusps in fore-and-aft line, by migration, rotation, or circumduction, of the two marginal cusps, outward in the upper, and inward in the lower jaw.[77] It will clarify the situation a great deal if we show graphically just how this occurs (*fig. 4*).

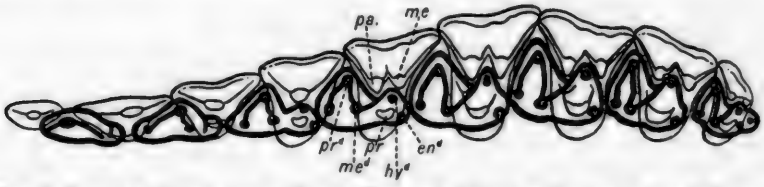

FIG. 5. DIAGRAM ILLUSTRATING (1) THE PROBABLE MODE OF ORIGIN OF THE MOLARIFORM PATTERNS OF PRIMITIVE PLACENTALS, AND (2) THE CORRELATED EVOLUTION OF UPPER AND LOWER TEETH. (*After Gregory*)

Successive stages are shown in passing from the simple anterior premolars, which have only the primary trigon, backward to the molars, in which the secondary trigon arises thru the inward growth of the "protocones" and the division of the primitive apex into two cusps, the para- and the metacones. This hypothesis is based on indirect evidence and awaits direct palæontological confirmation, as the upper molars of the oldest known placental mammals of the Paleocene had already acquired the secondary trigon in the upper molars and the expanded talonid of the lower molars.

Osborn[78] offers as final proof the following geological sequence:

GEOLOGICAL PERIOD	UPPER MOLAR TYPE	MAXIMUM IN PAIR	TOTAL CUSPS: UPPER, LOWER MOLARS
Triassic	Haplodont, protodont, triconodont, with single or grooved fangs	6 cusps	
Jurassic	Triconodont, tritubercular, with two or three fangs	8 cusps	1–2 styles
Cretaceous	Tritubercular	11 cusps	2 styles
Basal Eocene	Tritubercular, quatritubercular, and higher stages	12 cusps	3–4 styles
Upper Eocene	Tritubercular and all the derived types	12 cusps	6 styles

[77] Gregory, 22; pp. 254–6.

[78] Osborn, 39; p. 99. See also table 10.

Unfortunately, the Osbornian cusp nomenclature has not been universally followed. During the course of reading, the writer came across several systems of nomenclature, all of which are given below for purposes of correlation, and to aid those who otherwise might be confused:

Hypocone	postero-internal	distolingual	postero-lingual (or postero-palatal)
Metacone	postero-external	distobuccal	postero-buccal
Protocone	antero-internal	mesiolingual	antero-lingual (or antero palatal)
Paracone	antero-external	mesiobuccal	antero-buccal
Protoconid	antero-external	mesiobuccal	antero-buccal
Paraconid	(not in man)		
Metaconid	antero-internal	mesiolingual	antero-lingual
Hypoconid	postero-external	distobuccal	postero-buccal
Entoconid	postero-internal	distolingual	postero-lingual
Hypoconulid	postero-median	distal	postero-mesial (in a sagittal plane)

Recent authorities tend to bring in dorsal and ventral as replacing postero, and antero, etc., but they offer little aid in escaping the chaos created by the lack of uniform acceptance of Osborn's system.

Now, having seen a graphic presentation of the theory, and having digressed a bit to clarify the use of terms, let us observe the theory in detail, and endeavor to see if it "works," i.e., explains the origin of the human molar. The four major tenets of the Cope-Osborn theory may be stated as follows:[79]

1. The "tritubercular type," consisting in the possession of three main tubercles on the crowns of both upper and lower molars, disposed in triangles, is ancestral to many, if not all, of the higher types of molar teeth.

2. The tritubercular type arose from a single conical type by the addition of lateral denticles.

3. The "cusp addition principle," namely, the successive addition of new denticles, cuspules, or smaller cones on the sides of the original reptilian cone, accounts for lateral denticulation.

4. In the lower molars the reptilian cone is external and the two denticles internal, while in the upper molars the reverse is the case, namely, the reptilian cone is internal and the denticles are external.

These four points may be re-stated with greater clarity as follows:

[79] Osborn, 39; pp. 2–5.

(1) The lateral cusps on the reptilian cone gave rise to a triconodont type, not directly to a tritubercular type.

(2) The tritubercular type was evolved as the result of the circumduction of the cusps.

(3) In the lower molars the reptilian cone is external and the two denticles internal, while in the upper molars the reverse is the case, namely, the reptilian cone is internal and the denticles are external.

(4) Mesozoic tritubercular types are homologous as to cusps with the teeth of placentals.

From the very first this theory was attacked, especially with respect to the circumduction of the molars, as called for in the fourth major tenet above. Much of the adverse criticism took the form of the postulation of new theories. Many writers, however, while accepting some portions of the theory, rejected others. Their criticism took the form of a semi-revision. Representative among these is Gregory,[80] who in 1916 referred to the origin of the tritubercular molar as "still a very debatable matter." Wortman[81] and Gidley[82] agree with him in this. Together, the three have advanced what is known as the "premolar analogy theory." This theory was early noted by Osborn,[83] who in 1907 referred to the "embryological theory" as being the precursor of the "premolar analogy theory." It was observed by the proponents of the latter theory that in the embryo the protocone in the upper molar was later in development than the paracone. Arguing from this basis the assertion was made that the protocone was hence not the oldest phylogenetically. The oldest cusp is the paracone, and this is the homology of the reptilian cone. To quote Osborn: "The embryological theory, in brief, is to the effect that while in the lower molars the central reptilian cone remained external and the two denticles arose internally, forming a triangle, in the upper molars the reptilian cone remained at the antero-external angle (paracone) and the two denticles arose on the inner and posterior sides."[84] Gidley[85] presents much the same argument

[80] Gregory, 22; p. 249.
[81] Wortman, 10.
[82] Gidley, 21.
[83] Osborn, 39; pp. 6–7.
[84] Compare Wortman, quoted by Gregory, 23; p. 150.
[85] Gidley, 21; pp. 92–3.

when he holds the Cope-Osborn theory untenable "insofar as it involves the position of the protocone and the derivation of the trigonodont tooth from the triconodont stage through the shifting of the lateral cones outward in the upper molars and inward in the lower molars. . . . . The primary cone (as revealed in the embryo) is the main antero-external cusp, or paracone, having retained its position on the outside in most upper molars."

Gregory[86] likewise attacks the assertion that the primitive reptilian cone is on the inner side of the upper molars, and on the outer side of the lower molars. His argument is so concise and pithy that it warrants reproduction verbatim.

"First, the 'Premolar Analogy' assumes that the molars in pre-tertiary times passed through precisely the same stages of progressive modification that are observed in the premolars of Tertiary phyla. This leaves entirely out of account the possibility that the final resemblances between premolars and molars may have resulted from the convergent evolution of nonhomologous cusps.

"Secondly, in many Early Tertiary and primitive modern mammals as we pass backward from the simple conical upper first premolar through the progressively more complex second, third, and fourth premolars to the first molar, we observe that the main high cusp of the premolars, which apparently represents the tip of the reptilian tooth, stands in anteroposterior line not with the protocone of the molars, but with the paracone and the metacone. This tends to show that the paracone of the molars, and not the protocone, usually represents the tip of the original reptilian crown. If this is not the case we must suppose that the original summit of the upper molar crowns has been widely displaced inward, while the summit of the lower molar crowns has remained in the same anteroposterior line with that of the premolars, an hypothesis which appears to be irreconciliable with the observed interlocking relations of the upper and lower cusps and depressions in any primitive mammal.

"Thirdly, that the outer side of the upper molar crowns is older than the inner side, viz., that the region of the paracone and metacone is older than the region of the protocone, is clearly suggested also by the form of the deciduous molars and by the relations subsisting between the deciduous molars and the true molars in many families and orders of mammals. . . . . In every case observed the inner parts of the anterior upper

[86] Gregory, 22; p. 239 ff.

deciduous molars, namely the region of the protocone, seem to represent an ingrowth from the outer portion of the crown, more or less similar to the internal extension of the crown in the upper premolars. . . . . The evidence obtained from the deciduous dentition seems, therefore, to harmonize with the Premolar Analogy theory and to indicate that the 'protocone' is a derived and not a primary cusp.

"Fourthly, the view that one of the outer cusps (especially the paracone) and not the protocone, represents the summit of the reptilian upper molar is fully in accord with the embryological facts observed by Röse in the human tooth, by Tæker in the teeth of ungulates, by Leche in the teeth of marsupials, and especially by M. F. Woodward in the teeth of various insectivora. . . . . But while I am thus obliged to reject the fourth proposition of the Cope-Osborn theory of tritubercuIy, to the effect that the protocones of the upper molars represent the original tip of the reptilian molar crown, yet the transverse widening of the crown or ingrowth of the protocone must have been affected at a relatively early epoch, since it is fully developed not only in the Paleocene and Eocene placental mammals but also in the Upper Cretaceous marsupials.

"In conclusion, I continue to endorse the Cope-Osborn theory, insofar as it derives all the more complex molar patterns of typical placental mammals respectively from the 'tritubercular' and 'tuberculosectorial' types of upper and lower molars. But I am forced to reject that theory both in its explanation of the origin of the tritubercular type and in its identification of the origin of the tritubercular type and in its identification of the protocone as the summit of the haplodont reptilian molar. On the other hand, I now accept, in the main, the 'Premolar Analogy' Theory, as advocated especially by Wortman and Gidley, which holds that the paracone of placental mammals usually represents the summit of the originally haplodont crown and that the protocone is an outgrowth from the inner base of the crown."

Others who have written on the subject of the origin of the mammalian molar form are Duckworth,[87] Wiedersheim,[88] and Hopewell-Smith.[89] As a rule these authors contribute nothing original, contenting themselves with noting the observations of others, especially Cope-Osborn, and Wortman. Since Gregory's exposition of the theory in 1916 little more has been added. Hrdlicka, in 1920, asked

[87] Duckworth, 20; p. 283 ff.
[88] Wiedersheim, 49; p. 322.
[89] Hopewell-Smith, 28; pp. 136–44.

Wortman[90] to state his views on the subject. Wortman merely re-affirmed his early views. Gregory[91] in 1922, re-stated his position as follows:

1. In the triangular upper molars of early tertiary mammals, there are two principal "trigons:" (a) the *primary trigon*, consisting of the divided "original tip" (para-metacone) and the external cingulum; (b) the *secondary trigon*, comprising the inwardly grown "protocone" and the divided original tip (*Fig.* 5).

2. The homologue of the trigonid of the lower molars is not the *secondary*, but the *primary*.

It is evident from these principles that Cope's conception of the origin of the tritubercular molar probably is based upon a misconception by which the *secondary* trigon of the upper molar was viewed as corresponding with the primary trigonid of the lower molar. It follows that the protocone of the upper molars is in all probability not the oldest cusp of the mammalian molar crown. It has probably arisen and is functionally analogous with the talonid, or posterior part of the lower molars. No matter how much the Cope-Osborn theory may be attacked, it still stands a monument to the genius that conceived it. We must conclude that however the tooth pattern of the placentals may have originated, the cusp homologies *within the placentals* seem perfectly clear, and the Cope-Osborn nomenclature is an extremely clear method, and the only one in general use, to express these relationships.[92]

In addition to the foregoing two theories, viz., the Cope-Osborn and the premolar analogy, we must, however briefly, consider two other theories which hold the mammalian molar to have been derived from only one reptilian tooth: the polybuny theory, and the cingulum theory. The *first* was advanced by Forsyth-Major,[93] who, noting that primitive mammals were multitubercular, said that the tritubercular type had evolved through the loss of cusps. Duckworth shows that multituberculation was co-existent with the triconodont form of molar, and hence he is against the theory on the basis that the

[90] Wortman, 10; p. 178.
[91] Gregory, 23; pp. ix–x.
[92] See page 52.
[93] Duckworth, 20; pp. 292–4.

multitubercular type may have come from the triconodont. Osborn[94] points out that tubercular low-cusped crushing teeth are not primitive. This theory is virtually dead today. The *second* theory, i.e., that the cusps are the result of the upgrowth of the cingulum, is supported by Marett Tims,[95] Hrdlicka,[96] and Hopewell-Smith.[97] It might be mentioned, parenthetically, that even the strongest advocates of the tritubercular theory, recognize the importance of the cingulum. Thus Osborn says: "As is well known, the hypocone is an upgrowth from the cingulum. By its disappearance in some regions, and by its elevation into prominence in others, the form of a tooth may become profoundly modified, and it thus comes to be regarded as a sort of mother of cusps."[96]

Hrdlicka has done the most work with this theory, and it would be best if we observe his conclusions in full. While making a study of the teeth, particularly with reference to "shovel-shaped" incisors,[98] he noted what appeared to be an inherent tendency of "ridging" in the teeth. After a prolonged investigation he arrived at the following conclusions:[99]

"1. The crowns and cusps of the human and other mammalian teeth show in general an inherent tendency to ridging, or to *lophodonty* and *lophoconidy*.

"2. The functional rôle of the ridging is to strengthen the teeth and cusps and to assist trituration of food.

"3. There is but one fundamental pattern of ridging of both crowns and the cusps in the whole mammalian kingdom; which pattern, however, is subject to a wide range of modifications.

"4. The ridging is partly marginal (keilodonty) but in the main intermarginal (lophodonty, lophoconidy); and the latter is directly connected with an equally inherent and old triconodont tendency of the teeth and cusps.

"5. The intermarginal ridges are the axial ridges of the more or less

[94] Osborn, 39; p. 205.
[95] Tomes, 48A; pp. 335–6.
[96] Hrdlicka, 2; pp. 166–7. See 3.
[97] Hopewell-Smith, 28.
[98] Hrdlicka, 3.
[99] Hrdlicka, 2; pp. 166–7.

differentiated 'lobes' or 'cones,' the lobes or cones that in extreme cases would give the typical triconodont tooth, or a triconed cusp.

"6. The differences of the ridging in the crowns of the incisors or canines and the cusps of the premolars or molars, are merely those of degree.

"7. The median of the intermarginal ridges of a crown or a cusp is without exception the best developed and most frequent. It is the axial ridge of the 'protocone' or 'main lobe' and the main strengthening ridge of the crown or cusp as a whole.

"8. The depressions lateral to the intermarginal ridges are remnants of a keilomorphous feature of the surface, a separate condition.

"9. Phylogenetically, lophodonty and lophoconidy do not appear to be either remnants of, or reversions to, any primitive ancestral condition of teeth or cusps, but an inherent morphological tendency of progressive possibilities.

"10. Finally, the results of the study of these ridges, together with that of the cingulum[100] and the cusps, indicate the entire homology of the various teeth; the homomorphy of the crowns and the cusps; and the origin of the various teeth not by differentiation of a primitive triconodont type (Cope, Osborn), or by accretion of primitive teeth (Kükenthal, Röse, etc.), or from an original bicuspid, or 'dimere' form (Eterode, Bolk), but from monomere crowns with the cingulum, by the development, under functional call, from the cingulum, of additional cusps, with similar morphogenic endowments or possibilities as those of the older crown or cusp, and which gradually assume a stabilization and similar form with the older constituents of the tooth."

I have received from Dr. G. G. Simpson, of the Peabody Museum of Yale, a brief report of his researches on Mesozoic mammals. This material I have been unable to incorporate in the main body of this paper, so I take this opportunity of presenting it at this point. His conclusions, which he has graciously permitted me to add, are as follows:

"1. The essence of the Osborn-Cope theory lies in the fundamental nature of the tuberculo-sectorial molar. This may be considered as really demonstrated for the majority of mammals (that is, of Tertiary and later

[100] The cingulum is "the enamel swelling or belt that surrounds or embraces the crown of the tooth near its base, and from which at times are seen arising accessory cusps to the teeth." Hrdlicka, 2; pp. 167–8.

mammals). Difference of opinion as to how this pattern originated does not mean opposition to the Cope-Osborn theory. On the contrary, if a more firmly established theory of derivation can be proposed than the rather widely disallowed one advocated by Osborn up to 1907 the theory will be very strongly supported thereby in its main contention.

"2. The zalambdodont type of molar, as already pointed out by Mivart, Woodward, Leche, Gidley, and others is not homologous with the general tritubercular type of the primitive mammals.

"3. The protocone is not the oldest cusp of the mammalian molar. The original reptilian cusp has given rise by fission or unequal budding to the paracone and metacone. The protocone and the external cingular and stylar elements are secondary upgrowths from the base of the crown. All these cusps arose close to where they are now found, apparent changes of position, at least in the early stages of molar complication, being due almost entirely to changes in proportion of the tooth as a whole or of its various parts.

"4. There has hence been no cusp rotation. The triconodont molar type has nothing at all to do with the tritubercular (except of course as a pseudo-triconodont type may be derived by retrogression, e.g., in the seals). Neither has the *Spalacotherium* type anything to do with the true tritubercular type. The triconodonts and the symmetrodonts (an order including *Spalacotherium* and its allies) are not ancestral to any later mammals either directly or structurally, nor are they closely related to each other.

"5. The pantotheres are not tritubercular in molar structure and the term "trituberculates" so often applied to them is objectionable as being incorrect morphologically. They are in a very distinctly pretritubercular stage of evolution, and as a group are structurally ancestral to later marsupials and placentals, although most of the known members are rather aberrant. They do not have upper molars at all comparable with those of the zalambdodonts."

V. TEETH IN ANTHROPOLOGY

The teeth, long recognized as of the utmost importance by the palæontologist, are gradually being accepted by the anthropologist as being of almost equal importance in his field. Their use may be said to be, by and large, three-fold: comparative, historic, and racial.

1. Comparative study of the dentition of man and the higher apes

When one stops to consider the length of time involved in the mammalian deployment as it now obtains, one would not expect two such related forms as man and ape to differ markedly in their dental structure. And, taken by and large, they do not. It may be stated that "the teeth of the anthropoids resemble closely those of man. They are alike in number, $\frac{(2.1.2.3)}{(2.1.2.3)}$, and occlusion, but differ somewhat in form and position."[101] It may be added that the deciduous sets of man and ape resemble one another far more than do the permanent sets, and that of the anthropoids the gibbon is the farthest removed from the human dentition.[102]

The procedure to be followed in this section is somewhat as follows: we will first note the dentition of each of the anthropoids, and then, insofar as we have already viewed man's dentition (pages 12–22), will present the more salient points in which the two agree or differ.

Gibbon.[103] As in all the anthropoids, the dentition of the gibbon is adapted to a frugivorous diet. The gibbon is more primitive than the other anthropoids in that it has a sub-tritubercular type of upper molar, the hypocone being ill-developed. The molars are not as wrinkled as in the higher anthropoids. The lower molars are five-cusped as in the other anthropoids. The middle part of the crown of the lower molars, as in all primates, forms a basin for the reception of the internal cusps of the upper molars. The premolars are smallish and tend to be bicuspid. The canines are very large and sabre-like, and, as in the other anthropoids, are more fully developed in the male than in the female. The horizontal ramus of the gibbon is much more slender than in the higher anthropoids. The incisors are small, chisel-like, and procumbent. The median incisors are only slightly larger, and not excessively enlarged as in the other anthropoids.

Orang-utan.[104] The teeth are massive, adapted to a frugivorous diet. The upper molars are quadritubercular, and tend to be quadrilateral. The morsal surfaces of the crowns are excessively wrinkled,

[101] Hellman, 27; p. 20.
[102] Wiedersheim, 50; p. 157. Cf. Hellman, 27; p. 21.
[103] Gregory, 22.
[104] Gregory, 22; pp. 274–5.

more so than in any of the other anthropoids. The premolars are relatively "heavier" than in the gibbon. The canines are very large, more so in males than in females. The central upper incisors are very broad with flattened posterior faces. The upper incisors and canines form an evenly rounded arch. The mandible is massive with a high ascending ramus on which the condyle is above the level of the coronoid. The lower first premolar is less elongate than in the gibbon, but more elongate than in the chimpanzee. Its oblique antero-external slope is worn, as in other anthropoids, by the postero-internal face of the upper canine. The second lower molar tends to the molar pattern. The molars are five-cusped, with the crowns flatter than in the other anthropoids. The roots[105] of the orang teeth are extremely long, much more so than in the other anthropoids. In the order of orang, gorilla, and chimpanzee, the anthropoids tend to have supernumerary molar teeth, particularly so in the male sex, generally in the mandible. There is a marked space, or diastema, between the canines and the first premolars. This is true of all the anthropoids, with the exception that in the gibbon,[106] there are no diastemata in the lower jaw.

Chimpanzee.[107] The upper molars tend to retain the V-like ridges of the primitive tritubercular pattern. The anterior root of the molars is grooved as though it were tending to divide; again, we may here have two roots in the act of coalescing. The lower molars are five-cusped, and in the pattern of the crowns they distantly approach the human type,[108] although the antero-posterior diameter is still the greater, and the posterior moiety of the crowns is not expanded. The third upper and lower molars evidence signs of degeneracy. The upper molars are rounded in contour. The molars as a whole are crenated, with low cusps, more so than in the gorilla, but less than in the orang,[109] except in the lower molars. The upper premolars are of the normal anthropoid type, but are smaller. The premolar-molar rows are nearly parallel in the lower jaws, but diverge in the upper

[105] Duckworth, 20; p. 247.
[106] Hellman, 27; p. 24.
[107] Gregory, 22; p. 275.
[108] Hellman, 27; p. 26.
[109] Duckworth, 20; pp. 247–8.

jaws of old males, especially. The canines are stout tusks. The median upper incisors are very wide with large crenated crowns.

Gorilla.[110] The canines form great tusks, causing the lower premolar-molar series to diverge anteriorly. This condition, however, is practically limited to adult males. The incisors are narrow, the upper centrals being the widest.[111] The upper premolars are quite wide. The first lower molar, due to the heavy upper canine, has a well-worn antero-external face. The molars have conical cusps, higher than in the other anthropoids, and they are far less crenated. The upper molars have a large anterior and a smaller posterior moiety, though traces of the original trigonal pattern may be observed. In general the fundamental pattern of all the premolars and molars is substantially that of the other anthropoids. The occlusion,[111] as in the anthropoids, as a whole, may be either edge-to-edge, or overbite, with the former condition the more typical. The mandible is very massive, with a long, stout horizontal ramus and a broad ascending ramus.

To sum up, though the dentition of all the anthropoids is substantially the same, there are many points of variance:[111]

1. The incisors vary extremely in size.

2. The incisors vary also in form. In the gibbon there is a marked cingulum. In the orang this condition is not so pronounced, but there is extreme crenation. In the chimpanzee these crenations are less, while in the gorilla they are absent.

3. The incisors vary in position. In the gibbon they are almost vertical. In the orang there is a curve from apex to edge. In the chimpanzee this is less evident, while in the gorilla they are straight in their long axis and are prognathous.

4. The incisors of all occlude in overbite, or edge-to-edge.

5. The canines vary from the sabre-like appearance in the gibbon to the tusk of the gorilla.

6. The canines vary in position, in that there seems to be a rotation on the long axis as we pass through from gibbon to gorilla.

7. In all, the upper premolars are bicuspid, while the lower first is tuberculo-sectorial and the second molariform.

[110] Gregory, 22; pp. 276-7.
[111] Hellman, 27; p. 27.

8. The premolars are vertical in position, with an interlocking occlusion.

9. The molars are quadritubercular in the upper jaw. The hypocone is here added, while in the lower molars the paraconid is lost. The cusps in the gorilla are high and triangular, in the chimpanzee nipple-shaped, in the orang flat and little marked, and in the gibbon high and rounded. In form the molars are rhomboidal above and elongate below, rounded in the gibbon and orang, angular in the gorilla. The occlusion evinces two primitive characteristics, viz., the protocone occludes into the fossa of the talonid, and the hypocone into that of the trigonid.

Turning now to the dentition of man. We have observed, in our study of the permanent teeth (Division III, Section 3; Tables 4 and 5), the principal characteristics of each of the teeth of man. Our next question is, then, how much do these teeth differ from those of the anthropoids? Gregory[112] answers as follows: "When we compare the dentition, as a whole, of anthropoid and man, we find that they resemble each other in their heritage of ancient common characters, but differ widely in their habitus of recently acquired specialization." These specializations are, then, the only distinct differences between the two. They are so numerous, so diverse, so minute even, that one could write volumes on the subject. Gregory[113] has, perhaps, done more work on this problem than any one else, so that if we accept his conclusions we cannot be far from wrong. Man is differentiated from the anthropoids by the following characteristics:

(1) Shortening of the muzzle and symphysis.

(2) Retraction of the anterior teeth, the incisors becoming more erect, the canines decreasing in size.

(3) First lower molar reduced in size and markedly bicuspid.

(4) Development of a chin (a late feature).

(5) Increasing convergence of the opposite tooth rows, and widening of the intercondylar diameter of the mandible.

[112] Gregory, 23; p. 387.

[113] Gregory, 23; pp. 344 ff.; 369 ff.; 444 ff. The following are in fundamental agreement with his conclusions: Wiedersheim, 49; p. 324; Tomes, 48; p. 572 ff.; Todd, 47; p. 245 ff.; Hopewell-Smith, 28; pp. 93 ff. and 151–2; Duckworth, 20; pp. 248–55. See also Thompson, 46A; pp. 182–204.

(6) Rounding of the molar crowns, obliterating the anthropoid pattern. In some cases loss of the hypoconulid in the second and third lower molars. Third upper molar assuming a tritubercular pattern.

(7) Movement of the mandible changing from an oblique, transverse movement, to movements in all directions and of a partly rotary character (especially correlated with the reduction of the canines).

(8) A complexly interrelated series of changes connected with the assumption of the upright position and the great increase of the brain case. This influenced the dentition especially by changing the insertion area of the jaw muscles.

(9) A final adjustment of the dental arch to give an overbite in the incisors, and an increased tendency for each lower molar to articulate chiefly with only one upper molar.

(10) In brief, the skull and dentition of man in comparison with those of the anthropoids exhibit the following adaptive characters:

Enormous expansion and deepening of the brain-case
Extreme shortening of the face
Retraction of the front part of the lower dental arch
Reduction in the size of the dentition
Tooth row forming a more or less rounded arch
Canines not protruding much above the level of the other teeth
Anterior premolars transversely widened and bicuspid
Fusion of the premaxillaries with the maxillaries
Lower jaw with progressively protruding chin, early losing the inferior symphyseal ledge
Reduction of the supraorbital crest
Extreme retraction of jaws beneath brain-case
Articular eminence for the lower jaw small and strongly convex, permitting motion in all directions
Glenoid fossa very deep
Zygomatic arch feeble

In regarding the differentiation of man and the anthropoids it will not be amiss to note Simonton's conclusions regarding the mental foramen in anthropoids and man.[114] They are as follows:

1. Tendency for the foramen to lie in line with the lower second

[114] Simonton, 8A, pp. 419–21.

bicuspid. This was the case in all the groups except the Melanesians and the California Indians. The percentage of foramina occurring in line with the lower second bicuspid in the various groups is shown below.[115]

GROUP	PER CENT OF FORAMINA IN LINE WITH LOWER SECOND BICUSPID	GROUP	PER CENT OF FORAMINA IN LINE WITH LOWER SECOND BICUSPID
Arkansas Indians (108).....	72	Japanese (10).....	40
Kentucky Indians (150).....	56	Orangs (123).....	36
Chimpanzees (32).....	50	Whites (138).....	33
Eskimos (114).....	43	Negroes (42).....	28
Gorillas (43).....	41	Egyptians (160).....	26

2. Tendency for the foramen to be placed posteriorly, i.e., posterior to the second lower bicuspid.

GROUP	PER CENT OF FORAMINA POSTERIOR TO LOWER SECOND BICUSPID	GROUP	PER CENT OF FORAMINA POSTERIOR TO LOWER SECOND BICUSPID
Melanesians (68).....	53	Arkansas Indians (108).....	17
Negroes (42).....	42.8	Gorilla (43).....	16.2
Egyptians (160).....	42.5	Kentucky Indians (150)....	16
Chimpanzees (32).....	31	Orang (123).....	15.92
Japanese (10).....	30	Whites (138).....	15.2
Eskimos (114).....	19	California Indians (336)....	13

3. Tendency to multiple foramina. Multiple foramina occur in the following percentage of cases in the various groups:

Orangs (123).....	39	Whites (138).....	6
Gorilla (43).....	27	Kentucky Indians (150).....	5
Negroes (42).....	16	California Indians (336).....	2
Chimpanzees (32).....	15	Japanese (10)[116].....	0
Melanesians (68).....	11	Egyptians (160).....	0
Eskimo (114).....	8		

A tendency to the occurrence of three foramina arranged in the form of an equilateral triangle is rather noticeable in the gorilla, rare in the orang, and was not observed in the other groups.

[115] Figures in parenthesis indicate number of cases.

[116] Only a few specimens of Japanese were observed.

Hrdlicka[117] has undertaken a study, in man and the anthropoid apes, of the two principal dimensions of the crown in the lower first and second molars, about the most stable and representative of the molars. This study has revealed a series of hitherto unknown, or but partially known, facts of phylogenetic as well as ontogenetic interest, which may be summarized as follows:

In their actual and especially in their relative proportions, the lower M_1 and M_2 in man stand well apart from those of the anthropoid apes, yet the gap is not very great, for it is crossed by individual teeth from both sides, and is bridged to a large extent by the teeth of the early forms of man.

Except in fundamentals, the resemblances and differences between the teeth of modern man and those of the anthropoid apes are not necessarily nor even probably the ancestral relations, but are rather to be looked upon as parallel or divergent developments.

The most human-like teeth among the anthropoid apes are those of the chimpanzee, but this, as just said, does not necessarily mean a close genetic relation, for the teeth of man of today (as well as those of the chimpanzee) are not those of their early ancestry. Nevertheless, the similarities in size and to a large extent even in the crown index between the teeth of the two forms, is a very interesting phenomenon, and probably indicates a much closer relation in man and this ape in such habits as have influence on the size and form of the teeth, than has hitherto been appreciated.

The most radical present-day difference between these molars in man and the apes lies in the relative mass of the two teeth. In man M_2 is generally smaller than M_1, while in the apes M_2 is as a rule the larger. Judging from the teeth of early man the latter condition appears to be the older and to have existed also in man's ancestry.

The second important difference between these teeth in man and the apes is their relative shortness in man, which gives rise to a high crown index. In some human groups this relative shortness of the teeth is such that their average breadth actually exceeds the average of length.

Sexual differences in the teeth under consideration are more pronounced in the apes, particularly in gorillas and orangs, than in man.

[117] Hrdlicka, 5A.

On the other hand, man shows in general a rather primitive, relatively long M_1 in the females, which is much less in apes. This is well reflected in the crown index of these teeth which in man as a rule is smaller in the females than in the males, but in apes is smaller in the females of some species while equal or larger in other species.

There is enough in common in the detailed characteristics of the lower molars alone, as far as dealt with in this study, strongly to support the opinion of the far-ancestral unity of the whole primate group, including the forebears of man.

Among the apes the outstanding features of the lower M_1 and M_2 are:

(a) The great size and especially the length of the teeth in the gorilla, with a greater difference in the species in the crown index of the two sexes;

(b) Their great variability in all respects in the orang; and

(c) The marked differences both in absolute and relative proportions of the teeth of the Symphalangus and the gibbons. These would appear to be more of a family or at least of a sub-family than merely those of species or genera.

Table 11 graphically presents the differences with respect to the mandible.[118] It will be noted that the comparison is between *Dryopithecus* and man. This may be explained by the statement that the Dryopithecus dentition is with "minor modifications"[119] typical of that of the anthropoids.

2. Dentition of prehistoric man

When we consider prehistoric man we cannot expect any great variation from the present type of human dentition. What we might expect, and what we do find, is a condition which is more or less transitional between man and the anthropoids. The order in which the prehistoric dentition will be studied must not be construed as an indication of the antiquity of the subject under consideration. Rather, the various types will be considered with regard to their approximate age, and more specifically as far as possible with respect to the advance displayed by the dentition.

[118] Gregory, 23; pp. 504–5.

[119] Gregory, 23; pp. 377–8 and 387; Hellman, 27; p. 19. The "Dryopithecus pattern" is a five-cusped $M_1M_2M_3$ (Prd, Med, Hyd, End, Hyld), with cusps separated by furrows.

TABLE 11

Contrasts between Dryopithecus and man in the lower jaw and teeth

FEATURE	DRYOPITHECUS	MAN (TYPICAL)
Dental formula	$\frac{2.1.2.3}{2.1.2.3}$	$\frac{2.1.2.3\text{–}2}{2.1.2.3\text{–}2}$
Lower incisors	Slightly procumbent, not crowded	More erect, crowded, often more or less displaced
Diastema between lateral lower incisor and canine	Present	Closed
Diastema between lower canine and first premolar	Present	Closed
Crown of lateral lower incisors	Less expanded transversely, with remains of primitive tip	Expanded transversely, truncate at top
Lower canine	Pointed tip, projects considerably, above level of premolars	Obtuse tip, projects little above level of premolars
Axis of lower canine crown	Slightly inclined forward	Vertical
First lower bicuspid	Asymmetrical, high tip, two roots	Symmetrical, low tip, single root
Second lower bicuspid	Asymmetrical, high tip, high trigonid, low talonid	Symmetrical, low tip, reduced trigonid and talonid basis
First lower molar	Smaller than second, five cusps, "Dryopithecus pattern"	Longer than second, five cusps, and remnant of "D-pattern"
Second lower molar	Five cusps, "D-pattern"	Four cusps, plus-shaped pattern
Third lower molar	Longest of series, five cusps and "D-pattern"	Shortest of series, often four cusps, modified "D-pattern"
Proportions of lower molars	Long and narrow	Short and broad
Intercondylar diameter	Relatively narrow	Very wide
Lower dental arch	Parallel sides	Converging sides
Space for tongue	Contracted, narrow	Expanded, wide
Symphysis	Relatively long and sloping	Very short and vertical
Bony chin	Retreating	Protruding
Ascending ramus	Very wide	Narrow

Hesperopithecus.[120] Two molars of this type were found by Harold Cook, in Nebraska, in what is presumed to be a Pliocene deposit. The first or original molar is probably a second upper molar, while the second or paratype is probably a third molar. The second (?)

[120] Gregory and Hellman, 24 and 38.

upper molar will be considered here. The morsal surface is much worn, so much so in fact that the cusps are quite indistinguishable. In general, we find the primitive trigon, with a very weak talon, the hypocone being unusually small. This imparts to the tooth an aspect of trituberculy. The crown is much longer in its antero-posterior diameter, and has a rounded, triangular, shape. There are three roots, one internal, two external (medio-internal,[121] antero-external, postero-external). These roots have in common many characteristics of both man and anthropoids. So much so in fact that Osborn,[122] supported by Hellman, places *Hesperopithecus* with *Pithecanthropus* and man, while Gregory places the type with the gorilla-chimpanzee group. The whole problem of *Hesperopithecus* is still very debatable, and until additional evidence is found, it must be considered an open question as to whether we have here man or anthropoid.

Australopithecus Africanus.[123] The teeth consist of a practically perfect deciduous set, with the first upper and lower permanent molars. The incisors are small, in this being nearer man than the higher apes. The upper deciduous canine has an antero-posterior length of less than three-fourths that of the molar, while in the higher apes the reverse is true, i.e., the canine has a greater antero-posterior length than the first deciduous molar. The deciduous molars, as a whole, are nearer man than ape. The upper first true molar is essentially human and four-cusped, though it is relatively larger than a human tooth. The lower incisors, likewise, are quite human. The canine, on the other hand, betrays simian affinities in that it is fairly large and more pointed than in man. Similarly the lower first true molar presents a five-cusped (*Dryopithecus*) pattern which is distinctly simian. The tooth thus makes a close approximation to the first molar of the chimpanzee, though considerably larger. "The study of the teeth renders it pretty certain that *Australopithecus* stands somewhere between the chimpanzee and man."[124]

[121] In a transverse plane.

[122] See, however, Osborn: "*Hesperopithecus*, the first anthropoid Primate found in America." *A. M. N. H. Novitates*, 37, pp. 1–5, 1922.

[123] Broom, 15A; pp. 413–4. Hrdlicka (*A. J. P. A.*, 8, p. 390) says "teeth approach those of chimpanzee and man, not gorilla."

[124] Todd holds this type to be "typically anthropoid," so far as is known.

Pithecanthropus erectus. Here, as in the preceding case (*Hesperopithecus*), we also have widely divergent opinions as to the type represented by the teeth. Boule[125] and Miller[126] claim the teeth to be simian, while the general opinion of the American school is that they are human, or as Gregory expresses it, "subhuman."[127] The teeth found are three in number:[128] a premolar which has never been figured, and two molars. Boule says they are both third upper molars, right and left, while Gregory[129] maintains that we have a left upper second molar, and a right upper third molar. Both molars are larger than the human teeth today, and have strongly divergent roots, both simian characters. On the other hand, the antero-posterior diameter is not relatively so great as in the anthropoids. The right upper third molar (Gregory) distinctly approaches the "Dryopithecus-pattern," and has a weak metacone. The left upper second molar (Gregory) has a much reduced posterior moiety, a large paracone with buccal protrusion, and a bucco-lingual slope on the outer border of the crown. The morsal surfaces of both molars are greatly worn. The age of *Pithecanthropus* is a subject of great disagreement, some maintaining it to be Late Pliocene, others Early Pleistocene.

Heidelberg. Mandible and teeth found in 1907 in the Mauer Sands (generally accepted as Early Pleistocene) near Heidelberg. The mandible[130] is exceptionally massive, with a deep ascending ramus, and a complete lack of chin. The mandibular notch is not deep. The coronoid process is blunt, and below the level of the condyle, which has a large articular surface. The angle of the jaw, as well as the symphyseal region, are quite simian. The anterior portion of the jaw is quite restricted. The teeth are quite human.[131] The arch tends to be parabolic instead of U-shaped as in the anthropoids. There are no diastemata and the canines do not protrude above the level of the other teeth. The incisors tend to be vertical rather than procumbent. The premolars are small, the first lacking the

[125] Boule, 15; p. 103.
[126] Gregory and Hellman, 24; p. 527 ff.
[127] Gregory, 23; pp. 358–60.
[128] Boule, 15; pp. 102–3.
[129] Gregory, 23; pp. 358–60.
[130] Boule, 15; p. 150 ff.
[131] Boule, 15; p. 154 ff.; Gregory, 23; pp. 428–9.

"sectorial" form of the antero-external face. The molars are quite quadrilateral, the antero-posterior diameter being about the same as the bucco-lingual. The second molar is the largest, and all of the molars evince the "Dryopithecus-pattern." The fifth cusp, however, is already being wedged in between the two posterior cusps, preparatory to disappearing in later man (except in the first molar). In fact, the plus-shaped human molar can be faintly discerned in the third molars. The "bite" is edge-to-edge.

Piltdown. Portion (right side) of mandible, with first and second molars in place, found in 1912, and mandibular canine, found in 1913.[132] Referred to very early Pleistocene. The mandible has aroused a storm of comment. While the cranial bones are decidedly human, the jaw is just as decidedly simian. Boule[132] and Miller[133] incline to the view that this is a composite find, i.e., human skull, ape jaw, probably a chimpanzee. Hrdlicka,[134] on the other hand classes the jaw as belonging to "either a human precursor or very early man." The condyle, as well as the upper portion of the front half of the horizontal ramus, are missing. The ascending ramus is broad and the mandibular notch is not very deep. Hence the condyle must have been short. The mylo-hyoid groove is below the dental groove and there is no mylo-hyoid ridge (internal oblique line). The symphyseal region is probably simian, with a complete absence of chin. The canine[135] differs from a human canine in its larger dimensions, in the more raised, conical, and more compressed form of crown. The wear on its surfaces indicates a probable diastema. It probably protruded above the level of the other teeth. The first and second molars have a greater antero-posterior diameter, with a well-defined neck. The roots are typically molar-like and do not seem to diverge quite as much as in the anthropoids. The molars, as a whole, are larger than in modern man, and are definitely five-cusped, adhering here closely to the "Dryopithecus-pattern."

Neanderthal. We will here observe the dentition of the Neanderthaloid as a whole, making special reference, however, to the Krapina

[132] Boule, 15; p. 157 ff. (Cranial bones found also; 1911–1912 and 1915.)

[133] Miller, 7; p. 43.

[134] Hrdlicka, 4; p. 346.

[135] Miller and Gregory hold it to be an upper canine, closely approaching a female chimpanzee upper canine. Gregory, 23; p. 358.

and Rhodesian dentitions. Boule[136] notes that "the dentition of Neanderthal man does not differ in any important character from that of men of today." This is true with one exception. Taken as a whole, the Neanderthal dentition is marked by a condition known as "taurodontism,"[137] which means a special development of the roots and pulp cavity. This is occasioned, it is believed, by the heavy diet of the men of that time. This supposition is affirmed by the muscle attachments which indicate a heavy grinding motion of the jaw. As a result the teeth are rapidly worn down, and a study of the crown of the adult is rendered very difficult. The dental arches are very wide. The upper arch is about midway between the U-shape of the anthropoids and the parabolic shape of man. The lower arch is more human, this giving an edge-to-edge bite. The canines do not protrude above the level of the other teeth. The teeth, as a whole, are large, but this may be ascribed to the heavy diet. The upper molars are truly molariform, while the lower molars all present the "Dryopithecus-pattern" to about the same extent as does the Heidelberg jaw.

The *Krapina* teeth[138] are of especial interest in that the central upper incisors afford what is apparently a stage in the development of the mongoloid "shovel-shaped" incisors.[139] The *Rhodesian* skull[140] has an immense palate, but the teeth are of a normal human type. The lower jaw, however, must have been massive. All the teeth are affected with caries, a condition which has never been observed in fossil European skulls.

Grimaldi. Negroid type,[141] contemporaneous with Neanderthal. There is pronounced alveolar prognathism. The jaw is strong, with a thick corpus and a broad, low ascending ramus. The dentition is characterized by great size, and the arches do not diverge as in higher races. All the upper molars have four cusps, while all the lowers have five cusps, a distinctly primitive condition. The lower jaw narrows anteriorly.

[136] Boule, 15; p. 213.
[137] Boule, 15; p. 212; Gregory, 23; p. 441 ff.
[138] Gregory, 23; pp. 457–8.
[139] See page 80 of this paper.
[140] Boule, 15; pp. 482–6; classed by him as Neanderthaloid. Todd says not.
[141] Boule, 15; p. 271 ff.

Cro-Magnon.[142] The Cro-Magnon dentition seems to have conformed in all respects to the modern type. There was some alveolar prognathism, and, as a concomitant of this condition, we may postulate an edge-to-edge bite, a usual characteristic of prehistoric man. The chin was strongly developed. In keeping with the superb physique of this type the dentition averages a larger size than in modern man. This condition, however, must not be regarded as a primitive one, allied to the anthropoid type.

It remains but to mention the Talgai skull, and the Boskop skull. There are others, of course, but they are of such relative unimportance that we will not consider them here. The *Talgai skull,*[143] of Pleistocene age, exhibits pronounced facial prognathism. The palate is primitive, and the molar series are parallel. The canines are large and protrude above the level of the other teeth. The occlusal surfaces of the upper canine and the lower first premolar hint at a slight diastematic condition. The premolars and molars are large and tend toward the "Dryopithecus-pattern." The *Boskop skull,*[144] a Negroid skull of uncertain geologic age, presents a very heavy horizontal ramus with but a slight chin. Only one tooth is in position, the second left lower molar. It is so badly worn that an examination of the cusps yielded no clue as to the presence of primitive or advanced characters.[145]

3. Racial differences and their indices

In 1911 Hrdlicka[146] said, as we have noted, that "the type of human dentition can be said to be today, with few exceptions, radically everywhere the same. . . . . The lack of pronounced racial differences in teeth or dentition indicates strongly a unity of origin of mankind." Since these words were uttered it has been revealed that there are racial differences, either specializations or retrogressions, by which we can recognize racial types.

[142] Boule, 15; pp. 281–9.
[143] Boule, 15; pp. 369–71.
[144] Boule, 15; p. 392.
[145] The reader is urged to read Hopewell-Smith, 28; p. 152 ff., and Tomes, 48; p. 584 ff., for excellent general discussions of primitive dentition.
[146] Quoted by Gregory, 23; p. 476.

Before going into a detailed study of racial types it would be profitable to generalize "high" and "low" characteristics, with regard to the dentition. "*Low*"[147] may be generalized as follows: esognathism, or edge-to-edge bite; crown of incisors vertical, roots deflecting backward; incisors often shovel-shaped; palate U-shaped; chin not prominent; massive jaw, wide ascending ramus; microdont, molar cusp formula, $\frac{4\text{–}4\text{–}4}{5\text{–}5\text{–}5}$; third molars erupting early and of large size; Carabelli's cusp[148] frequent on M^1 and M^2 and these molars rhomboid; "Dryopithecus-pattern" in lower molars and traces in premolars. "*High*" may be generalized as follows: orthognathism, or normal overbite; shovel-shaped incisors rare; palate paraboloid to hyperboloid; chin prominent, with delicate jaw; microdont, molar cusp formula, $\frac{4\text{–}3\text{–}3}{4\text{–}4\text{–}4}$; third molars erupt late or suppressed; Carabelli cusp not common; M^2 rounded, tritubercular; lower molars with plus-shaped pattern; premolars distinctly bicuspid.

Before going further it is advisable to record a simple method of noting position, etc., of a tooth by means of an ordinary formula.[149] We will take the second molar as an example: M^2—second left maxillary molar; ^2M—second right maxillary molar; M_2—second left mandibular molar; $_2M$—second right mandibular molar. To check teeth present or missing:

Permanent:

Right								Left								
8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	upper
8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8	lower

Deciduous

Right					Left					
e	d	c	b	a	a	b	c	d	e	upper
e	d	c	b	a	a	b	c	d	e	lower

[147] Gregory, 23; pp. 479–80.

[148] Jeanselme, 29A; 29B. The cusp proceeds from the cingulum and is found on the first, and occasionally the second, permanent molar. It is also found on the second deciduous molar.

[149] Hopewell-Smith, 28; pp. 73–4.

In a discussion of dentition with respect to race, we should note the form of the palate, or upper dental arch, and the form of the lower dental arch. Of these the form of the palate and upper dental arch are so closely related that we will treat them, for purposes of discussion, as one. It was formerly held that the size of the teeth occasioned the form of the arches, but Hellman[150] has attacked this theory, and advances the view that form and position give rise to the obtaining dental arch. He points out that the different form and position of the teeth in the maxillary and mandible have occasioned, even in the same individual, two divergent arches. Hopewell-Smith[151] supports him in this when he points out that the upper arch is elliptical, while the lower is parabolic in outline. Again, Hellman[152] points out that the arches of the anthropoids may take on any one of six shapes, even though a measurement of the teeth reveals a discrepancy far from sufficient to account for the variation. It is a fact that the lower arch of the "Mousterian youth"[153] was greatly changed as to shape, because the permanent canine was impacted and the deciduous canine retained. Position and form determined this variation.

Form and position thus become vitally important in differentiating racial types. Insofar as function,[154] i.e., diet, affect the form and hence the position, we may expect of different peoples, different types of arch. It must be noted here that, as in the teeth, nutrition, i.e., malnutrition, plays a great part in determining bony structure, especially in the maxillae and mandible. Should[155] the teeth in the lower incisor arch be evenly spaced, there will be a tendency to the edge-to-edge bite, or esognathism. On the other hand, should the lower incisors be crowded there will result an overbite, or orthognathism. The edge-to-edge bite[156] is typical of the Amerind and the Eskimo. The over-bite is present in the blacks, is usually present in whites and Hindoos, and is an extreme condition in the mongoloids.

[150] Hellman, 25; p. 27.
[151] Hopewell-Smith, 28; p. 233.
[152] Hellman, 25; p. 4.
[153] Gregory, 23; p. 450.
[154] Hopewell-Smith, 28; p. 26. Also, Wiedersheim, 49, p. 314; 50, pp. 156–7.
[155] Gregory, 23; p. 473.
[156] Hellman, 27; p. 27. Todd, 47, pp. 149–53, says overbite is present in 95 per cent of Englishmen.

The form[157] of the palatal arch becomes a good racial characteristic. The incisors and canines of the whites, lying in a flat curve, give an open divergent arch as in *A* (*fig. 6*). In the blacks the incisors and canines are spread over a greater area, giving an arch as in *B*, more nearly approaching the U-shape of the anthropoids. The yellow races are intermediate. Occasionally the arch in the blacks may converge back of the second molar as in *C*.

The palatal index is as follows:[158] The length of the hard palate is taken from the alveolar point to the posterior nasal spine (*fig. 7*). The width is taken either from the inside or the outside of the molars.

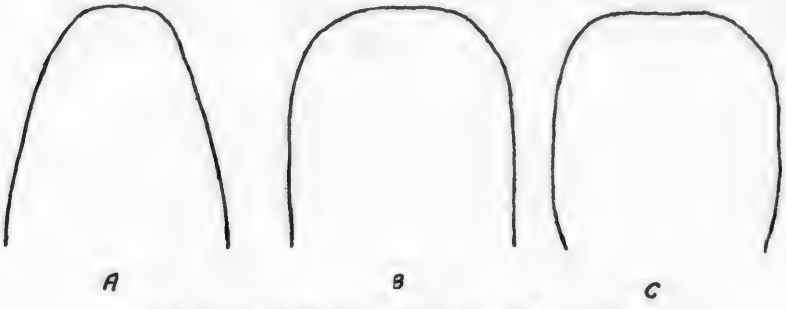

FIG. 6. DIAGRAMS SHOWING FORMS OF THE PALATAL ARCH

A—Open divergent arch: whites. *B*—Arch more nearly approaching *U*-shape of anthropoids: blacks. *C*—Arch convergent back of second molars: occasional in blacks.

Broca and Duckworth, who used the outside width, give the following figures (average):

$\frac{\text{Width} \times 100}{\text{Length}}$				
	French Basque	79	Eskimo	68
	Arabs	75	Guinea Negro	65
	Polynesian	73	New Caledonia	63

It was formerly held that a brachycephalic individual would have a wide palatal arch, and a dolycocephalic person a narrow arch. But in 1918 Sullivan[159] showed that "the principle of dolicocephaly and

[157] Hopewell-Smith, 28; p. 232; Leavitt, 33; p. 469.
[158] From class notes on 4–21–25.
[159] Quoted by Gregory, 23; pp. 472–3.

brachycephaly, in itself, is not sufficient to explain the form of the alveolar arch."

The measurements to be taken on the palate[160] are as follows: *Breadth of upper alveolar border c. g.*[161] Landmarks: external surface of alveolar border, on each side. If there are any exosteses on the border they are to be avoided by placing the points of the instrument above the same. The measurement to be taken is the maximum transverse separation of the alveolar borders.

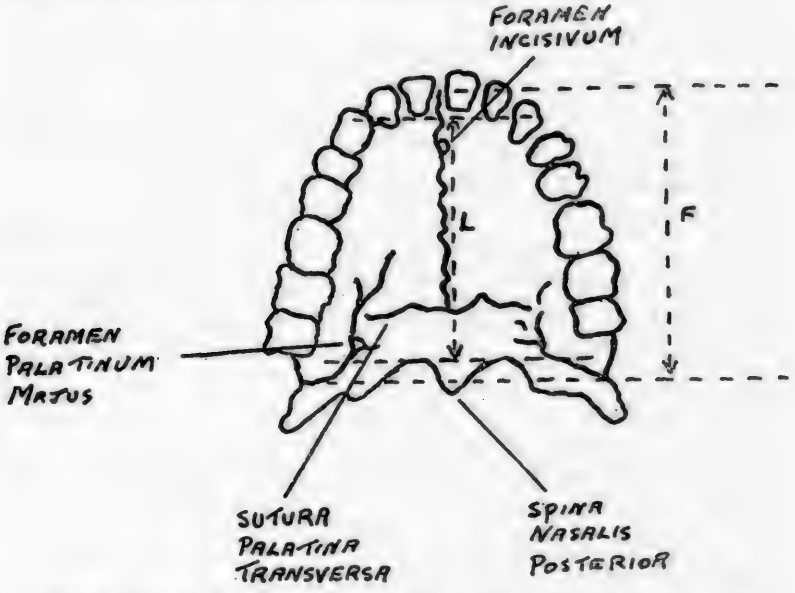

FIG. 7. DIAGRAM SHOWING MEASUREMENTS FOR THE DETERMINATION OF THE PALATAL INDEX

Length of alveolar arch (*F*, *Fig. 7*, *c. g.*). Landmarks: anteriorly—anterior surface of the alveolar borders between the two incisors; posteriorly—middle of transverse line connecting the posterior extremities of the alveolar border. (This transverse line is obtained by placing a wire as deep as possible on each side in the notch which

[160] Cran. Meas. 1, pp. 53–4.

[161] "c.g."—compas glissiere, the sliding compass.

separates the alveolar border from the pterygoid process. This gives the maxillo-alveolar index (see palatal index):

$$\frac{\text{Maximum breadth of alveolar border} \times 100}{\text{Length of alveolar arch}}.$$

Length of palate (*L, Fig. 7, c. g.*). Landmarks: anteriorly—median point of line tangent to the posterior alveolar border of median incisors; posteriorly—median point of transverse line connecting the most anterior points of the notches in the posterior border of the palate.

Breadth of palate c. g. Distance between the (internal) alveolar borders between the second molars. It must be noted that in the whites and mongoloids the transverse palatine suture is an irregular straight line, while in the blacks, and especially the Papuans, it curves anteriorly, encroaching upon the maxillary process.

Turning now to the teeth we are faced with the necessity of dividing our material. Hence we will consider individual teeth, indices, and general measurements. First, individual teeth. Hrdlicka[162] observed eruption of the teeth in both white and Indian children, and concludes as follows:

Deciduous teeth

1. Incisors same
2. First molar and canine first in whites
3. Second molar and completion of set first in Indians

Permanent teeth

1. Incisors and premolars same
2. Canines earlier in Indians
3. Second molar much earlier in Indians
4. Third molar averages earlier in Indians

Hrdlicka[163] further observes that the eruption of *deciduous teeth* among whites is generally completed before the end of the third year, that of the *permanent teeth* before the thirtieth year. Among primitive peoples (possibly even primitive whites), the process, at least so far as the permanent teeth are concerned, is somewhat speedier, being with few exceptions accomplished by or even before

[162] Quoted by Gregory, 23; p. 476.
[163] Hrdlicka, 1A; pp. 409–10.

the twenty-second year. A full set of teeth in a skull is therefore a good sign that adult life has been reached, or nearly reached; but an absence of one or two third molars may exist in the white, and more rarely even in a primitive man, well into the adult stage, and such teeth may fail to appear altogether. *Table 12* gives the periods of eruption of both sets of teeth among civilized whites (after Bean, Bednar, Cherot, Gray, Matiegka, and Suk, Roese, Steiner, Vogel, Welcker, etc.).

Suk[164] has done the most comprehensive work on the problem of the eruption of the teeth as a racial criterion. His work was with

TABLE 12

Eruption of teeth in whites

FIRST DENTITION	PERIOD	PERMANENT DENTITION	PERIOD
	months		*years*
Median incisor, lower	4–8	First molar, lower	4–7
Median incisor, upper	8–11	First molar, upper	5–8
Lateral incisor, upper	8–11	Median incisor, lower	5–8
Lateral incisor, lower	12–15	Median incisor, upper	5–8
First molar, upper	9–21	Lateral incisor, lower	6–10
First molar, lower	12–21	Lateral incisor, upper	6–10
Canine, upper	16–24	Anterior premolar, upper	7–14
Canine, lower	16–25	Canine, lower	8–14
Second molar, upper	20–36	Anterior premolar, lower	8–15
Second molar, lower	0–36	Posterior premolar, upper	9–15
		Posterior premolar, lower	9–15
		Canine, upper	9–16
		Second molar, lower	10–17
		Second molar, upper	10–17
		Third molar, lower	15–30
		Third molar, upper	17–30

whites (children of Prague) and Negroes (Zulus), and he observed not only eruption, but also decay. His conclusions and the most important of his tables (*13–18*) are presented on the pages that follow.

1. The main period of eruption of each permanent tooth, or the time during which the majority of a given tooth erupt (Bean's "physiological standard"), generally covers about two years; but the total period of eruption differs widely with the different dental

[164] Suk, 45B; pp. 351–88.

TABLE 13

Beginning and end of eruption of permanent teeth in Negroes (Zulus)

TEETH	UPPER				LOWER			
	Order of eruption	Beginning	Eruption of majority	End	Order of eruption	Beginning	Eruption of majority	End
Males								
		year	*year*	*year*		*year*	*year*	*year*
Med. incisors	II	Before 5 (?)	5–6	8	II	Before 5 (?)	5–6	6
Lat. incisors.....	III	5	7–8	8	III	5	6–7	8
Canines.....	V	8	10–11	13	IV	8	10–11	13
Ant. premolars...	IV	8	10–11	12	V	8	10–11	13
Post. premolars...	VI	8	10–11	12	VI	8	10–11	12
First molars.....	I	Before 5 (?)	5–6	8	I	Before 5 (?)	5–6	8
Second molars....	VII	10	11–12	13	VII	9	11–12	14
Third molars.....	VIII	13	18–20	(?)	VIII	13	17–19	(?)
Females								
Med. incisors....	II	Before 5 (?)	6–7	7	II	Before 5 (?)	5–6	7
Lat. incisors.....	III	5	7–8	8	III	6	6–7	8
Canines.....	V	8	9–11	13	IV	8	9–10	13
Ant. premolars...	IV	8	9–10	12	V	8	9–10	12
Post. premolars...	VI	8	9–11	12	VI	8	9–11	13
First molars	I	Before 5 (?)	6–7	—	I	Before 5 (?)	5– 6	—
Second molars....	VII	9	11–12	—	VII	9	11–12	13
Third molars.....	VIII	12	18–20	(?)	VIII	12	17–19	(?)

TABLE 14

Beginning and end of eruption of permanent teeth in whites (Prague)

TEETH	UPPER				LOWER			
	Order of eruption	Beginning	Eruption of majority	End	Order of eruption	Beginning	Eruption of majority	End
		year	*year*	*year*		*year*	*year*	*year*
Med. incisors.....	II	5	7–8	8	II	5	6–7	7
Lat. incisors.....	III	7	8–9	11	III	Before 6 (?)	8	10
Canines.....	VI	9	11–12	15	IV	8	10–11	14
Ant. premolars.....	IV	7	10–11	14	V	8	10–12	15
Post. premolars	V	8	10–12	15	VI	8	11–12	15
First molars.....	I	5	6–7	8	I	Before 5 (?)	5–6	7
Second molars.....	VII	10	12–14	17	VII	10	11–13	17
Third molars.....	VIII	17	19 (?)	(?)	VIII	15	18 (?)	(?)

elements—three to eight years. There are no essential differences in this respect among the whites, except perhaps for a slight precocity in the children of Prague. In general girls are more precocious than

TABLE 15

Beginning and end of eruption in different races (years)

TEETH	AMERICAN BOYS (BEAN)	AMERICAN GIRLS (BEAN)	GERMAN-AMERICAN BOYS (BEAN)	GERMAN-AMERICAN GIRLS (BEAN)	CECH BOYS, PRAGUE (MATIEGKA, SUK)	DIFFERENT EUROPEAN BOYS (ROESE)	FILIPINO BOYS (BEAN)	FILIPINO GIRLS (BEAN)	ZULU BOYS (SUK)	ZULU GIRLS (SUK)
Upper										
Med. inc. .	7–9	6–9	6–11	7–10	5–8	5.5–11.5	b. 5–9	b. 5–9	b. 5–8	b. 5–7
Lat. inc. . .	7–11	7–12	7–11	7–11	7–11	6 (?)	b. 5–11	b. 5–9	b. 5–8	5–8
Canine. . . .	10–14	9–15	10–14	8–15	9–16	7.5–15	b. 5–11	5–13	8–13	8–13
Ant. premol. .	8–16	8–13	8–14	8–13	7–14	6.5–14.5	5–14	10–13	8–12	8–12
Post. premol. .	9–16	8–14	9–14	8–14	8–15	6.5–15	5–15	10–13	8–12	8–12
First molar	6–9	6–8	6–9	5–7	5–8	5– 9.5	b. 5–10	b. 5–9	b. 5–8	b. 5–7
Second molar. . .	12–16	10–15	11–16	11–16	10–17	9–15	5–14	10–15	10–13	9–12
Third molar. . .	—	16 (?)	—	—	17 (?)	—	13 (?)	12 (?)	13 (?)	12 (?)
Lower										
Med. inc. .	6–8	5–8	6–11	5–9	5–7	5–10	5–9	b. 5–9	b. 5–6	b. 5–7
Lat. inc. . .	7–10	6–9	7–10	7–10	6–10	6–12	5–10	b. 5–9	5–8	5–8
Canine. . . .	9–13	8–13	10–14	8–12	8–14	7–15	5–11	b. 5–9	8–13	6–13
Ant. premol. .	9–14	9–14	10–14	8–14	8–15	7–14.5	5–14	5–13	8–13	8–12
Post. premol. .	8–16	9–15	10–14	9–15	8–15	7–15	5–15	10–13	8–12	8–13
First molar	6–8	5–8	6–7	5–8	5–7	5–10	b. 5–12	b. 5–9	b. 5–8	b. 5–6
Second molar. . .	11–17	10–16	10–16	10–14	10–17	9–15	5–14	5–13	9–14	9–13
Third molar. . .	—	16 (?)	—	14 (?)	15 (?)	—	13 (?)	14 (?)	13 (?)	12 (?)

boys, and colored races more precocious than whites. The Filipinos and Zulus have a full set of teeth at eighteen to twenty years of age, and the American Indians but a little later.

2. The beginning and end of eruption in the lower jaw is somewhat earlier and the main period of eruption is a little shorter than in the upper jaw.

3. In general the earlier a type of tooth makes its appearance, the shorter will be its main period of eruption.

TABLE 16

"The time of eruption," or the period of the most rapid eruption, of the permanent teeth in different races (years)

TEETH	AMERICAN BOYS (BEAN)	GERMAN-AMERICAN BOYS (BEAN)	AMERICAN GIRLS (BEAN)	GERMAN-AMERICAN GIRLS (BEAN)	CZECH BOYS, PRAGUE (MATIEGKA, SUK)	FILIPINO BOYS (BEAN)	ZULU BOYS (SUK)	ZULU GIRLS (SUK)
Upper								
Median incisor	7–8	7–8	7–8	7–8	7–8	—	5–6	6–7
Lateral incisor	8–10	8–9	8–9	7–9	8–9	—	7–8	7–8
Canine	11–12	11–12	10–11	10–12	11–12	5–9	10–11	9–11
Anterior premolar	10–11	10–12	9–11	9–11	10–11	5–10	10–11	9–10
Posterior premolar	10–12	10–12	10–11	10–11	10–12	7–11	10–11	9–11
First molar	6–7	6–7	5–6	6–7	6–7	—	5–6	6–7
Second molar	12–14	11–14	12–13	12–13	12–14	10–11	11–12	11–12
Third molar	—	—	—	—	19 (?)	17–20	18–20	18–20
Lower								
Median incisor	6–7	6–7	5–6	6–7	6–7	—	5–6	5–6
Lateral incisor	7–9	7–9	7–8	7–8	7–8	—	6–7	6–7
Canine	11–12	11–12	9–11	10–11	10–11	5–9	10–11	9–10
Anterior premolar	10–12	11–12	9–11	10–11	10–12	10–11	10–11	9–10
Posterior premolar	11–12	10–13	10–11	11–12	11–12	10–11	10–11	9–11
First molar	6–7	6–7	5–6	6–7	5–6	—	5–6	5–6
Second molar	11–14	11–14	10–12	11–12	11–14	10–11	11–12	11–12
Third molar	—	—	—	—	18 (?)	17–18	17–19	17–19

4. On the whole eruption proceeds in the right side a little in advance of the left.

5. Teething proceeds gradually but not regularly. There is a sudden leap of acceleration between the eleventh and twelfth years in whites, and between the ninth and tenth in Zulu boys (eighth and ninth in Zulu girls).

6. Regarding decay of teeth, there is little difference among the groups of whites compared, and with regard to the types of teeth affected there are but small differences between whites and Negroes.

TABLE 17

Permanent teeth according to their involvement by decay among children of Prague and the Zulu

TOOTH	JAW	SCHOOL CHILDREN, PRAGUE ♂	ZULU ♂	ZULU ♀	TOOTH	JAW	SCHOOL CHILDREN, PRAGUE ♂	ZULU ♂	ZULU ♀
		Age: 6–19	Age: 5–20 and more				Age: 6–19	Age: 5–20 and more	
		per cent	*per cent*	*per cent*			*per cent*	*per cent*	*per cent*
First molar.....	Lower	42.9	22.8	31.8	Second molar	Upper	1.9	10.1	7.3
First molar.....	Upper	29.2	12.7	13.9	Ant. premolar	Lower	1.0	1.3	1.3
Second molar...	Lower	5.3	19.0	17.2	Canine.....	Upper	0.8	—	1.3
Post. premolar..	Upper	4.3	—	4.0	Lat. incisor...	Lower	0.3	—	—
Ant. premolar...	Upper	4.1	2.5	2.0	Canine.....	Lower	0.1	—	—
Lat. incisor.....	Upper	3.6	2.5	5.9	Med. incisor	Lower	0.1	—	—
Post. premolar..	Lower	3.4	7.6	5.2	Third molar...	Upper	—	6.3	2.6
Med. incisor....	Upper	2.5	1.3	3.3	Third molar...	Lower	—	13.9	4.0

TABLE 18

Decay of permanent teeth

SEX	AGE	NUMBER OF CASES	UPPER JAW			LOWER JAW			TOTAL		
			Number of permanent teeth	Decayed permanent teeth		Number of permanent teeth	Decayed permanent teeth		Number of permanent teeth	Decayed permanent teeth	
				Number	Per cent		Number	Per cent		Number	Per cent
School children of Prague											
♂	6–19	694	8,199	823	10.03	8,368	941	11.47	16,567	1,764	10.64
Zulus											
♂	5–20	489	5,739	28	0.48	5,878	51	0.86	11,617	79	0.68
♀	5–20	511	6,329	61	0.97	6,481	90	1.38	12,720	151	1.18

But there are considerable discrepancies as to the number of decayed teeth between these groups, the white children having more than ten times as many decayed teeth as the Negroes.

7. Decay of teeth is most frequently bilateral, which indicates internal as well as external causes.

8. At the age of eighteen years there are only 10 or 15 per cent of

TABLE 19

Percentage of total series with permanent teeth erupted

In nine and twelve year Mexican children (Sullivan)

TEETH	THIRD MOLAR	SECOND MOLAR	FIRST MOLAR	SECOND PRE-MOLAR	FIRST PRE-MOLAR	CANINE	LATERAL INCISOR	MEDIAL INCISOR
Upper right								
9 year G.		—	100	6	27	2	94	99
9 year B.		2	100	9	21	5	84	100
12 year G.		64	100	88	96	86	99	100
12 year B.		53	100	73	90	73	100	100
Upper left								
9 year G.		1	99	12	25	8	94	99
9 year B.		2	100	8	27	5	84	100
12 year G.		64	100	90	96	85	99	100
12 year B.		51	100	74	89	73	100	100
Lower right								
9 year G.		4	100	12	30	24	99	100
9 year B.		5	100	8	25	23	97	100
12 year G.		77	100	86	95	92	100	100
12 year B.		71	100	73	86	89	100	100
Lower left								
9 year G.		4	100	11	27	25	98	100
9 year B.		6	100	5	20	18	97	99
12 year G.		77	99	88	95	95	100	100
12 year B.		72	100	72	88	89	100	100
All uppers								
9 year G.		1	99	9	26	27	94	99
9 year B.		2	100	8	24	5	84	100
12 year G.		64	100	89	96	85	99	100
12 year B.		52	100	74	89	73	100	100
All lowers								
9 year G.		4	100	11	29	24	98	100
9 year B.		5	100	7	21	21	97	99
12 year G.		77	99	87	95	94	100	100
12 year B.		72	100	72	87	89	100	100

individuals among the whites in large cities with a faultless set of teeth, while among Zulus 85 to 94 per cent of such individuals were found.

TABLE 20

Percentages of deciduous teeth present in Porto Rican boys aged seven to fifteen (Spier)

AGE	UPPER JAW					LOWER JAW		
	Inner incisor	Outer incisor	Canine	1st molar	2nd molar	Canine	1st molar	2nd molar
7	29	70	96	89	93	80	77	77
8	16	37	70	76	82	55	67	65
9	—	9	61	46	63	32	40	45
10	—	14	42	26	63	24	38	41
11	—	3	24	17	42	14	11	33
12	—	—	13	5	18	4	7	18
13	—	2	10	4	11	2	5	13
14	—	1	—	—	1	—	—	1
15	—	—	—	—	—	—	—	—

TABLE 21

Percentages of permanent teeth present in Porto Rican boys aged seven to nineteen (Spier)

AGE	UPPER JAW							LOWER JAW				
	Inner incisor	Outer incisor	Canines	1st bicuspid	2nd bicuspid	1st molar	2nd molar	Canines	1st bicuspid	2nd bicuspid	1st molar	2nd molar
7	46	13	—	4	—	93	—	16	—	—	84	—
8	84	33	20	27	8	100	—	36	11	2	98	—
9	100	82	30	54	28	100	9	50	40	20	95	12
10	100	80	41	65	32	100	12	70	49	29	99	17
11	100	96	62	83	56	100	35	75	79	58	100	47
12	100	100	77	94	79	100	63	88	81	70	100	77
13	100	100	89	95	87	100	80	98	95	84	100	79
14	100	100	97	100	99	100	95	99	99	98	100	95
15	100	100	100	100	100	100	95	100	100	93	100	90
16	100	100	100	100	97	100	100	100	100	100	100	94
17	100	100	100	100	100	100	97	100	100	100	100	100
18	100	100	100	100	100	100	96	100	100	100	100	100
19	100	100	100	100	100	100	100	100	100	100	100	100

Sullivan,[165] observing nine- and twelve-year-old Mexican boys and girls of Tucson, Arizona, and Spier,[166] observing Porto Rican school children, noted the eruption of the teeth as shown in *Tables 19*,

[165] Sullivan, 45D.
[166] Spier, 45C.

20 and *21*. Hrdlicka[167] has also noticed the tendency for the mongoloids to have "shovel-shaped" incisors, due to a development of the ateral borders of the ventral side of the crown. This condition is extremely prominent in the upper median incisors. The mongoloids possess it to a marked degree, with the Negro intermediate, and the whites the least. Sullivan[165] has observed the enamel rim on the incisors of Mexican school children, as shown in *Table 22*. The enamel rim on the upper incisor teeth was found in varying degrees in only about 40 per cent of the series and in a marked degree in from only 10 per cent to 12 per cent.

TABLE 22

Percentage occurrence of enamel rim on the incisors of Mexican school children

	9-YEAR GIRLS	9-YEAR BOYS	12-YEAR GIRLS	12-YEAR BOYS
Enamel rim on upper incisors				
Lateral incisors:				
Rim absent	45	52	51	70
Trace	11	15	15	19
Medium	15	9	18	8
Marked	10	11	6	3
Total	81	87	90	100
Mesial incisors:				
Rim absent	45	52	49	64
Trace	10	18	14	20
Medium	19	10	19	11
Marked	11	13	7	4
Total	85	93	89	99

The whites[168] tend to lose the third molars, with the yellows next, and the blacks last. The situation is exactly reversed, however, with regard to the frequency of anomalous conditions, viz., supernumerary teeth, etc. Among the Negroes there is a tendency, in the lower molars, to retain the five-cusped "Dryopithecus-pattern." There is also a marked tendency for the molars, both upper and

[167] Hrdlicka, 3; pp. 456–7. Also quoted by Gregory, 23; p. 476.

[168] Gregory, 23; p. 476; Wiedersheim, 50; p. 159.

lower, to increase in size as we go from the first to the third.[169] The upper second molar of the Eskimo, through the loss of the hypocone assumes a triangular form, with the apex in an antero-buccal position.[170] Sullivan[171] observed the number of cusps on the second lower molar, with the following results:

GROUP	PERCENTAGE	
	5 cusps	4 cusps
Tarascan Indian (Mexico)	76.8	23.2
Australian	73.0	27.0
Negro	34.0	66.0
So. India	16.6	83.4
Lapplander	15.0	85.0
European	6.0	94.0
Alaman	3.0	97.0
Hungarian	2.0	98.0

Schultz[172] has associated alveolar prognathism with the length of the nasal spine. He finds that in the Negroes the nasal spine is 2.6 mm. long; in prognathous Europeans, 4.0 mm.; in orthognathous Europeans, 5.5 mm. The teeth, then, are the cause of this racial difference in the nasal spine.

There are two principal indices with regard to the teeth—the dental index and the gnathic index. In the former[173] the dental length is obtained by measuring between the anterior surface of the first premolar and the posterior surface in the third molar in the upper jaw, and comparing this with the basi-nasal length (basion to the alveolar point). The index is: $\frac{\text{Dental length} \times 100}{\text{Basi-nasal length}}$.

Microdont 42 – ; mesodont 42–44; megadont 44 plus. In general, the whites are microdont, the yellows mesodont, and the blacks

[169] Duckworth, 20; p. 251; Wiedersheim, 50; p. 159; Todd, 47; pp. 149–53.
[170] Gregory, 23; p. 479.
[171] Sullivan, 9; p. 256. Cf. Tomes, 48; pp. 581–2.
[172] Schultz, 8; pp. 336–8.
[173] Bryce, 16; p. 134; Duckworth, 20; p. 251; Hopewell-Smith, 28; pp. 167–71; Tomes, 48, p. 605.

megadont. The chimpanzee averages 47.9, the orang 55; the gorilla 54, and the gibbon 41.7.

The gnathic index[174] is obtained by comparing the basi-alveolar length (basion to the alveolar point), with the basi-nasal length (basion to nasion), giving the latter the value of 100. The index is:

$$\frac{\text{Basi-alveolar length} \times 100}{\text{Basi-nasal length}}.$$

Orthognathous 98 – ; mesognathous 98–103; prognathous 103 plus. In general, whites are orthognathous, the yellows mesognathous, and the blacks prognathous.

Azoulay and Regnault[175] measured the difference between the length of the lower border of the median upper incisor and the length of a wire placed parallel to its upper border. Their results follow:

RACES	NUMBER OF SPECIMENS	DIFFERENCE
Apes (chimpanzee and gorilla)	5	3.04
Various Negroes	41	2.39
New Caledonians, New Hebrides	13	2.19
Australians	10	2.00
Polynesians	14	2.01
Andamanese and Chinese	13	1.78
Europeans	18	1.61
Hindoos, Bengalese	7	1.27

Hrdlicka[176] has worked out a crown index, with reference to the first and second lower molars. The measurements are taken with the teeth in situ. The length is the mesio-distal diameter, along the middle. The breadth is the bucco-lingual diameter at right angles to the length and to the height of the tooth. The length should be taken with a needle-point compass, reading the measurements off on a standard scale. The breadth is taken by an accurate compas glissiere, with flattened branches on one side. The index is:

$$\frac{\text{Breadth} \times 100}{\text{Length}}.$$

[174] Bryce, 16; p. 133; Hopewell-Smith, 28; p. 172; Tomes, 48; pp. 581–2.
[175] Quoted by Gregory, 23; p. 478.
[176] Hrdlicka, 4A; pp. 195–216.

Dolichodont 90−; mesodont 90–100; brachydont 100 plus

RACE	M_1	M_2	RACE	M_1	M_2
Whites			*Anthropoids*		
Germans	90.4	91.6	Chimpanzee	93.2	95.0
"Europeans"	95.2	97.9		93.1	94.5
Americans	92.0	94.1			
Hungarians	97.2	96.1	Gorilla	88.9	87.7
Swedes	90–110	90–110		80.4	81.2
Yellows			Orang	93.1	95.5
Amerind	98.9	99.0		90.9	95.9
Chinese	101.8	100.0			
Eskimo	97.8	97.3	Gibbon (Hylobates)	82.4	87.7
				88.0	87.7
Blacks					
"Negro"	92.9	87.0			
Caledonians	87.4	94.6			
Melanesians	96.0	98.7			
Australians	102.5	96.1			

Thus the whites are mesodont, the yellows tend to be brachydont, while the blacks are undecided. The gorilla and gibbon are dolichodont, the chimpanzee and orang are mesodont.

The angle in the mandible, formed by the meeting of the corpus with the ascending ramus, is at once an indication of age and a racial criterion. The angle in the white is about 90°, in the yellow about 110°–120°, and in the blacks is over 120°. With respect to age Hopewell-Smith[177] gives the following summary:

The angle at birth is 175°.

At four years of age it is 140°.

In the adult white it approaches 90°.

In old age it is nearly 170°.

The measurements on the mandible[178] are as follows: *Bicondylar breadth c. g.* Landmarks: the most external points on each condyle; the separation of these points constitutes the measurement.

Bigoniac breadth c. g. Landmarks: the gonions, or points of the angles formed by the ascending branches with the body of the lower

[177] Hopewell-Smith, 28; pp. 277–8. Cf. Bryce, 16; pp. 104–5.

[178] Cran. Meas. 1; pp. 55–7.

jaw. The separation of the angles is measured by applying the compass to their external surface.

Length (height) of ascending branch c. g. Landmarks: superiorly —the uppermost point of the condyle; inferiorly—the gonion, but as it is frequently very difficult to determine this point, it is best to take the intersection of the lines prolonging the inferior and posterior borders of the bone. The measurement is obtained by permitting the lower jaw to rest on its inferior border, and the rod of the sliding compass along the posterior border.

Breadth of ascending ramus c. g. (a) Minimum breadth (*fig. 8, m*): The minimum distance between the anterior and posterior borders of the ramus. (b) Maximum breadth (*fig. 8, M*). Landmarks:

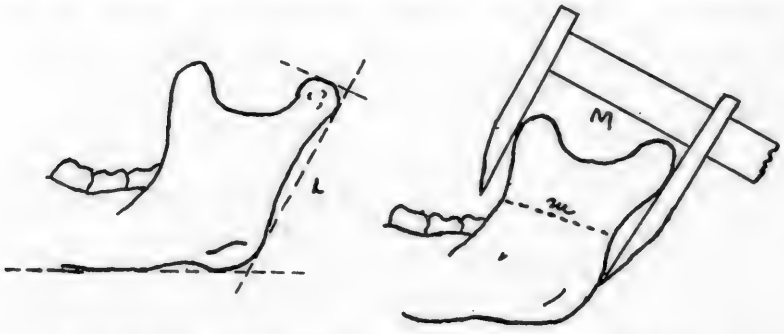

FIG. 8. DIAGRAM SHOWING LINES OF MEASUREMENT ON THE MANDIBLE

anteriorly—the most prominent point on the anterior border of the coronoid process; posteriorly—the farthest point on the posterior border of the bone. The measurement is obtained by applying one of the branches of the sliding compass tangently to the posterior border of the lower jaw, and bringing the other branch in contact with the anterior border of the coronoid process.

Height of symphysis c. g. Landmarks: in the median plane—superiorly the highest point of the alveolar border (between the median incisors); inferiorly the inferior border of the symphysis. Measure the actual distance between the two points, not in projection.

Height of body of lower jaw c. g. The same technique, but the

measurement is taken in a vertical plane, between the first and second molars.

Maximum thickness of body of lower jaw. The maximum separation of the internal and external surfaces of the bone in the plane between the first and second molars.

Mandibular angle. The angle between the posterior and inferior borders of the bone. To be measured by Broca's goniometre, and according to the technique advised by him.

4. Summary of human dentition: evolution and present deployment

The material about to be given was adapted from Gregory.[179] Only that bearing on the dentition is presented.

Conspectus of the Species and Chief Races of the Hominidae

PITHECANTHROPUS

Pithecanthropus erectus. Skull top almost gibbon-like; referred M^2 and M^3 very large.

PALÆANTHROPUS

Homo heidelbergensis. Mandible of great size with no bony chin; ascending ramus very wide. Dentition human, allied to Neanderthal type.

Homo neanderthalensis. Skull large; low retreating forehead, great supraorbital tori; skull wide posteriorly. Jaw stout, retreating chin; dentition "taurodont." Palatal arch horse-shoe shaped, wide.

EOANTHROPUS (? HOMO)

Homo dawsoni. Skull large, forehead steep, small, if any, supraorbital tori. Cranial walls very thick. If lower jaw correctly associated, it and dentition very much like that of a chimpanzee.

HOMO SAPIENS

A. *Cro-Magnon and other dolicho. Upper Palæolithic Races.*

1. *H. sapiens Galley Hill.* Skull very dolicho. Jaw with well-formed chin. Lower molars slightly taurodont with cusp formula 5,5,5; antero-posterior diameter of molars the greatest.

[179] Gregory, 23; p. 480 ff.

2. *H. sapiens Brunn-Predmost.* Skull dolicho. Forehead retreating, large supraorbitals. Chin prominent. Orbits broad, low. M_1 five-cusped. M_2 tend to plus-pattern.

3. *H. sapiens Cro-Magnonensis* (*aurignacensis*). Skull with reduced supraorbitals. Dolicho, with broad face, heavy zygomatic arches; nose narrow. Chin excellent. Dental arches and dentition of relatively high type.

B. Negroids

4. *H. sapiens Grimaldiensis.* Skulls negroid, dolicho. Dentition macrodont, low type. Upper arch narrow; marked prognathism.

5. *H. sapiens Boskop* (*H. capensis Broom*). Compared with Cro-Magnon and Bantu skulls by Haughton.

6. *H. sapiens Bushman.* Skull dolicho, forehead steep. Cheek bones high, nose broad, orthognathous. Dentition occasionally primitive; lower molars crenated.

7. *H. sapiens niger.* Sub-races: Negrito, Negro, Melanesia. Dolicho to brachycephalic (Andamanese). Forehead often "bombed" in Negroes. Nose broad. Prognathous. Dentition macrodont (Melanesian) to microdont. Palatal arch U-shaped (Melanesian) to V-shaped.

8. *H. sapiens tasmanianus.* Tasmanians (extinct). Skull subdolicho; face broad, nose broad and flat; prognathous. Palatal arch sometimes U-shaped.

9. *H. sapiens australianus.* (a) Talgai, Queensland; (b) recent. (a) Skull low type, large palate and teeth, marked prognathism. (b) Skull dolicho, heavy supraorbitals; nose broad; prognathous. Dentition macrodont, low. Palatal arch varies, often U-shaped. Molar cusp formula low, $\frac{4\text{–}4\text{–}3\frac{1}{2}}{5\text{–}5\text{–}5}$.

C. Melanoids or Mediterranoids

10. *H. sapiens veddalis.* Veddas of Ceylon. Skull very dolicho. Orthognathous. Nose broad, depressed at root.

11. *H. sapiens dravidicus.* Peoples of the Deccan. Skull dolicho or mesocephalic. Palatal arch V-shaped. Molar cusp formula varies $\frac{4\text{–}4\text{–}4}{5\text{–}5\text{–}5}$ to $\frac{4\text{–}3\text{–}4}{4\text{–}4\text{–}4}$. Two sub-races: (a) platyrrhine, (b) leptorrhine.

12. *H. sapiens indo-afghanis.* Peoples of northwest India. Skull dolicho; nose thin, prominent.

13. *H. sapiens ethiopicus.* Ethiopians of northwest Africa. Skull dolicho. Nose prominent. No prognathism.

14. *H. sapiens mediterraneus.* Usually dolicho.

Sub-race A: *mediterraneus berber.* Berbers of northern Africa. Nose straight. Skull not as long as Arab.

Sub-race B: *mediterraneus arabicus.* Arabs. Nose aquiline. Skull dolicho. Dentition modern.

Sub-race C: *mediterraneus littoralis.* Med. shore of northern Italy, southern France, Spain. Nose straight, fine. Skull mesocephalic.

Sub-race D: *mediterraneus Ibero-insularis.* Spain, Portuguese, south Italians, Sicilians, Corsicans, and dolicho Neolithic peoples of western Europe and British Isles. Skull dolicho. Nose straight.

D. Ainu

15. *H. sapiens ainu.* Ainu of northern Japan. Dolicho or mesocephalic; face broad, orthognathous. Nose concave, broad.

E. Xanthoids

16. *H. sapiens nordicus.* Nordic race, now centering in Sweden. Dolicho. Nose prominent, straight. Dentition modern.

F. Alpinoids

17. *H. sapiens assyroideus.* Represented on Assyrian monuments, now mixed in Persians, Assyrians, Armenians, Jews. Brachycephalic. Nose in form of figure 6, thick at top.

18. *H. sapiens armenianus.* Represented on Hittite monuments, now mixed in Armenians, Arabs, Turks, Greeks. Skull hypicephalic, with flattened occiput (planoccipital). Nose large, long, narrow, protruding.

19. *H. sapiens adriaticus.* Coast of northern Adriatic—Bosnia, Dalmatia, Croatia, Tyrol, etc. Very brachycephalic.

20. *H. sapiens alpinus.* Western Europeans. Very brachycephalic, nose sharp. Palate wide, dentition modern.

G. Mongoloids

21. *H. sapiens Turco-Tartar.* Turkish race. Skull very brachycephalic. Nose straight.

22. *H. sapiens mongoloideus.* Mostly brachycephalic. Face broad, high cheek bones, orthognathous. Nose short, concave. Upper incisors shovel-shaped. Palate wide.

23. *H. sapiens eskimo.* Skull dolicho with "scaphoid," compressed

vault. Cheek bones high. Palate wide. M^2 small with three cusps. Lower jaw massive.

H. Amerinds

24. *H. sapiens amerind.* American Indians. Skull often brachycephalic, sometimes dolicho. High cheek-bones. Palate often broad. Nose straight, aquiline. Upper incisors shovel-shaped. Molars, large M_1, with "Dryopithecus-pattern."

I. Oceanians

25. *H. sapiens indonesianus.* Indonesian tribes of Borneo, East Indian Archipelago, and Philippines. Dolicho to brachycephalic. Nose flat, often concave. Cheek bones often high.

26. *H. sapiens polynesianus.* Hawaii to New Zealand. Skull brachycephalic or mesocephalic; nose prominent; face long, elliptical.

In the following pages there is given a final summary presenting the entire history of the evolution of the human dentition. It is taken verbatim from Gregory.[180]

TWENTY-SIX STRUCTURAL STAGES IN THE ASCENT OF MAN AND IN THE EVOLUTION OF THE HUMAN DENTITION

Description of Stages 1–26

1. PRIMITIVE JAWLESS FISH. Known relatives: Silurian anaspid ostracoderms (BIRKENIA, etc.).
   Life zone: Freshwater streams, etc. Locomotor habitus: fish-like, but without pectoral and pelvic fins.
   Food habits: probably sucking in minute organisms and organic matter.
   Mouth and jaws suctorial.
   Cartilaginous gill-arches not developed or not calcified.
   Teeth, none.
   Skin covered with denticles or flattened scutes.
2. PRIMITIVE GNATHOSTOME OR JAW-BEARING FISH. Known relatives: primitive Devonian sharks (CLIMATIUS, CLADOSELACHE).
   Life zone: freshwater streams, etc. Locomotor habitus: fish-like, with pectoral and pelvic fins of fin-lappet origin.
   Jaws cartilaginous, calcified, derived from modified gill-arches and operated by modified gill-arch muscles.

[180] Gregory, 23; pp. 508–520.

Jaws, temporal region and whole body covered with skin bearing shagreen denticles.

Teeth derived from enlarged shagreen denticles, formed in many successive sets on skin covering the jaws.

3. PRIMITIVE CROSSOPTERYGIAN. Example: Devonian rhipidistian fish, OSTEOLEPIS.

Life zone: streams and swamps. Locomotor habitus: fish-like; pectoral and pelvic fins feather-shaped, with fleshy axis supported by cartilage rods.

Food habits predatory.

Gill-arch or primary jaws covered with ossified skin.

Jaws hyostylic, that is, supported by large hyomandibular.

Temporal region with continuous imperforate osseous dermal covering, including intertemporal, supratemporal, squamosal, quadratojugal and jugal.

Teeth sharply differentiated in form from scales, covering margins and inner sides of jaws and roof of mouth.

Marginal teeth pointed, with complexly infolded bases (labyrinthodont).

A series of dermal bones covering opercular region and underside of throat.

4. PROGRESSIVE CROSSOPTERYGIAN. Example: Upper Devonian rhipidistian fish, EUSTHENOPTERON.

Life zone: streams and swamps. Locomotor habitus: fish-like; pectoral fins fan-shaped, with abbreviate, thick, fleshy axis, supported by skeleton of procheiropterygial type; pelvic fins of similar construction but narrower.

Food habits, jaws and skull, differing only in details from stage 3.

5. PROTETRAPOD. (Transitional from rhipidistian fish to primitive tetrapod.) Known only from a foot-print (THINOPUS ANTIQUUS March) from the Upper Devonian of Mauch Chunk, Pennsylvania.

6. PRIMITIVE AMPHIBIAN. Example: Lower Carboniferous stegocephalian, LOXOMMA.

Life zone: swamps. Locomotor habitus: primitive tetrapod type, with short, pentadactylate extremities.

Food habits predatory.

Jaws autostylic; upper jaw attached to base of cranium by basipterygoid processes; maxilla and dentary of moderate size.

Temporal region imperforate.

Opercular and gular elements lost; skull otherwise much as in stage 4.

Teeth much as in stage 4.

Palate in primitive forms much as in stage 4, in later Amphibia becoming widely open.

7. PRIMITIVE COTYLOSAURIAN REPTILE. Example: Upper Carboniferous cotylosaur, EOSAURAVUS.

Life zone: swamps. Locomotor habitus: primitive reptilian type.

Skull of EOSAURAVUS not known, but skull of Lower Permian SEYMOURIA will serve to represent this stage.

Otic notch (between tabular and squamosal bones well developed).

Temporal region imperforate, with separate intertemporal and supratemporal bones.

Jaws and teeth much as in stage 8.

8. PROGRESSIVE COTYLOSAURIAN REPTILE. Example: captorhinid cotylosaurs of the Permian.

Life zone: mostly dry land. Locomotor habitus: primitive reptilian type.

Food habits insectivorous, or perhaps feeding on crustaceans.

Jaws autostylic; maxilla and dentary much as in stage 7.

One of the coronoid and one of the splenial series lost.

Temporal region with imperforate bony covering; inter- and supratemporal bones lost. Otic notch lost.

Palate with A-shaped brace formed by pterygoids and quadrates.

Ectopterygoids forming downwardly projecting guards to prevent lateral displacement of the mandible.

Teeth losing the labyrinthodont structure, generally small and peglike, becoming protothecodont.

9. PRIMITIVE PELYCOSAUR (THEROMORPH): Permian. Example: MYCTEROSAURUS.

Life zone: dry land. Locomotor habitus: primitive lizard-like type.

Food habits insectivorous to carnivorous.

Skull more compressed, vertically deeper.

Jaws autostylic; maxilla and dentary becoming larger, dentary with a coronoid process.

Temporal region perforate, a temporal opening (the lateral temporal fenestra) lying below the postorbital-squamosal arch and above the jugal-squamosal arch.

Orbit bounded posteriorly by the postorbital-jugal bar; zygomatic arch jugal-squamosal arch) homologous with that of mammals.

Palate braced as in stage 8.

Teeth conical, compressed, thecodont, often differentiated into incisors, canines and a postcanine series.

10. Early Mammal-like Reptile. Example: Moschops (a specialized side branch).
    Life zone: dry land. Locomotor habitus: somewhat as in pelycosaurs, but body well raised off the ground in walking.
    Skull deep vertically.
    Jaws autostylic.
    Coronoid process of dentary meeting large surangular.
    Temporal region much as in stage 9.
    Teeth in two successional series, an outer and an inner one.
    Front teeth specialized (in Dinocephalia), with high tip and very large basal swelling.
11. Intermediate Mammal-like Reptile. Examples: primitive gorgonopsians of the Permian of South Africa.
    Food habits predatory.
    Ascending coronoid process of dentary becoming more prominent.
    Teeth compressed recurved.
    Pterygoids relatively weaker, quadrate reduced in size.
    Temporal opening lying below postorbital squamosal arch and above jugal-squamosal arch.
12. Advanced Therapsid or Theriodont. Example: cynodont reptiles of the Triassic of South Africa.
    Life zone: dry land. Locomotor apparatus: approaching monotreme mammalian type.
    Food habits predatory.
    Dentition differentiated into incisors, canines, premolars and molars.
    Deciduous and permanent series as in mammals.
    Cheek teeth compressed, incipiently triconodont, or with widely oval ridged upper molars articulating with sub-circular lower molar crowns.
    Each tooth supported by a single root.
    Dentary the predominant element of the lower jaw; post-dentary elements (angular, surangular, articular and pre-articular) becoming much reduced in size.
    Quadrate small, its dorsal process received into a deep pocket in the squamosal.
    Ascending ramus or coronoid process of dentary of very large size, the whole dentary bone approaching in form the mammalian mandible, but the mandibular condyle not yet developed. Temporal region essentially mammal-like, with mammalian temporal fossæ; zygomatic arch formed by squamosal and jugal and postorbital.

Postglenoid and post-tympanic processes of squamosal developed.
Maxilla vertically deepened, in broad contact above with nasals.
A secondary palate, of submammalian type.
Pterygoids weakened posteriorly and barely reaching the quadrates.

13. PRIMITIVE MAMMALIAN STAGE. Examples: DROMOTHERIUM, MICROCONODON; Upper Triassic, North America.
Food habits insectivorous.
Skull unknown, but probably retaining many characters from stage 12.
Lower jaw with small condylar process, implying the establishment of a secondary articulation between the squamosal and the dentary; otherwise ascending ramus of dentary much as in stage 12.
Post-dentary elements probably reduced.
(In earlier stages the quadrate and articular bones were probably connected more or less directly with the tympanic membrane, as they are in recent reptiles. This condition persists in mammals where the quadrate has given rise to the incus and the articular to the malleus.)
Teeth differentiated into incisors, canines, premolars and molars.
Molar crowns compressed, protodont, with high central cusps and small anterior and posterior cusps.
Division of roots into anterior and posterior moieties more or less completely effected.

14. PRE-TRITUBERCULAR STAGE. Example: AMPHITHERIUM, of the order Tituberculata, Lower Jurassic, England.
Food habits insectivorous.
Skull not known, but probably without postorbital bone; with an elongate facial portion slightly deflected upon the low braincase.
Mandible with well defined pedunculate condyle and distinct angular process, the latter not inflected; inclination of coronoid process to body of dentary steeper; coronoid process wide, recurved above; condyle slightly above level of cheek teeth; mandible deeply grooved on inner side for reduced Meckelian cartilage and inferior dental nerve and vessels.
Dental formula: $I\frac{4}{4}\,C\frac{1}{1}\,P\frac{5}{5}\,M\frac{6}{6}$
Cheek teeth supported by anterior and posterior roots; premolars with simple, compressed, conical crowns and incipient talonids; molars with well defined trigonid and small talonids on inner surface of crown; protoconids asymmetrical, the metaconids directly medial to the protoconids. Upper molars of AMPHITHERIUM not known,

but, from evidence afforded by later trituberculates, they must have been triangular in form, separated by triangular interdental spaces; apex of each molar homologous with that of the premolars; as shown in PERALESTES and DRYOLESTES of the Upper Jurassic; the primary apex, together with the outer border of the crown, forming the primary trigon.

15. HYPOTHETICAL STAGE. Undiscovered ancestral insectivorous placentals ("Bunotheria") of the Cretaceous period.

Food habits insectivorous.

Dental formua: $I\frac{3}{3}\ C\frac{1}{1}\ P\frac{4}{4}\ M\frac{3}{3}$

Premolars retaining the primary trigon, but posterior upper premolars with small internal spur, the serial homologue of the future protocones.

Upper molars triangular, the apex of the primary trigon beginning to divide into two cusps, the para- and metacones. Lower internal spurs from the basal cingulum foreshadowing the future protocones.

Lower molars with high trigonids fitting into interdental spaces, and small talonids, narrow transversely, and bearing entoconid only.

The zalambdodont insectivore PALÆORYCTES of the Paleocene represents a structural survivor of this hypothetical ancestral group, which, in turn, may have been derived from the lower Jurassic trituberculates, especially AMPHITHERIUM, by the reduction in number of the molars from six to three.

16. INSECTIVOROUS PRE-PRIMATE. Possibly represented by INDRODON of the Paleocene. NOTHODECTES is a side branch of this group, with specialized front teeth.

This pre-primate stock is represented in the existing fauna by the tree-shrews (family Tupaiidæ), which are extremely primitive in many characters.

Life zone: arboreal. Locomotor apparatus: adapted for active arboreal life.

Food habits insectivorous-frugivorous.

Dental formula: $I\frac{2}{2}\ C\frac{1}{1}\ P\frac{4}{4}\ M\frac{3}{3}$

Incisors, canines and first two premolars all simple, with single roots, conical tups, and internal cingulum. In p^3, p^4, the internal cingulum gives rise to the internal spurs ("deuterocones," homologous with "protocones" of molars).

In p_3, p_4 the posterior cingulum gives rise to the talonids; p^4 and p_4 of sub-molariform type.

In this stage the primary trigon of the upper molar has lost its triangular appearance through the division of its apex into para- and metacones and the reduction of the outer side of the crowns, including the external cingulum cusps. The secondary trigon has arisen through the development of the internal spurs, or protocones, and the division of the para- and metacones. These changes are correlated with the transverse widening of the talonids, the development of a hypoconid and its interjection between the para- and metacones in occlusion, and with the further expansion of the protocones; the talonid basins into which the protocones fit have also widened and are wider than the trigonids.

Interdental spaces between the upper molars becoming crowded by the spreading of the protocones, in correlation with which the paraconids of the lower molars become reduced.

17. PRIMITIVE LEMUROID STAGE, represented in many respects by PELYCODUS and NOTHARCTUS. Eocene, North America.

Life zone: arboreal. Locomotor apparatus: adapted for perching and leaping in the trees. Pes with grasping hallux.

Food habits insectivorous-frugivorous.

Dental formula: $I\ \frac{2}{2}\ C\ \frac{1}{1}\ P\ \frac{4}{4}\ M\ \frac{3}{3}$

Incisors and canines not aberrantly specialized. First and second premolars with simple conical cusps; third and fourth upper premolars retaining the primitive trigonal apex; upper molars tri- to quadritubercular.

In the Notharctidæ the postero-internal cusps arise by fissure from the antero-internal cusps, but in the related Adapidæ they arise in the normal manner from the internal cingulum.

Lower molars tuberculo-sectorial, with small trigonids and wide talonids.

Skull with primitive elongate face, not sharply inclined to the basis cranii.

Orbit bounded posteriorly by postorbital processes of frontal and malar.

The American Northarctidæ are possibly ancestral to the South American monkeys, but not to the Old World series, including man. Nevertheless they illustrate the transition from the primitive menotyphlan insectivorous to the primitive primate stage.

18. PRIMITIVE PRO-TARSIOID. Represented in certain characters by OMOMYS and HEMIACODON. Middle Eocene, North America.

Life zone: arboreal. Locomotor apparatus: adapted for leaping in the trees, but limbs not excessively elongate. Pes with grasping hallux.

Food habits insectivorous-frugivorous.

Dental formula: $I\ \frac{2}{2}\ C\ \frac{1}{1}\ P\ \frac{3}{3}\ M\ \frac{3}{3}$

Skull with orbits, braincase and auditory parts moderately but not extremely enlarged.

Lower incisors gently procumbent, not enlarged. OMOMYS and HEMIACODON somewhat too specialized in the enlargement of the lower central incisors and other details, but in the general form of the premolars and molars they afford relatively primitive conditions for two divergent lines of specialization leading on the one hand to the New World series (Platyrrhinæ) and on the other hand to PARAPITHECUS and the Old World group.

First upper and lower premolars already eliminated and second becoming very small. Third and fourth upper molars showing tendency to become bicuspid.

Third and fourth lower premolar with posterior cingulum-talonid in an arrested stage of evolution, incipient trigonids asymmetrical, the metaconid of p_4 foreshadowing the lingual cusp of the homologous tooth in the higher primates.

Upper molars tritubercular, with conical para- and metacones, small proto- and metaconules, a cingulum-hypocone and an antero-internal cingulum.

Lower molars with small trigonids and enlarged hypoconids. An antero-external cingulum.

19. PROGRESSIVE TARSIOID. Upper Eocene. Not in direct line but represented in certain characters by NECROLEMUR.

Life zone: arboreal. Locomotor apparatus: adapted for leaping in the trees. Pes with grasping hallux, but without great elongation of tarsus of known tarsioids.

The differences separating NECROLEMUR and MICROCHOERUS from any of the New World or Old World monkeys are numerous and important, and there is no evidence for deriving any of the higher types directly from this source. Nevertheless these genera exhibit certain important advances in the direction of the Old World primates, among which may be noted the development of quadrate

upper molars with subequal anterior and posterior moieties; the development of hypoconulids in the lower molars; the final loss of the paraconids in the lower molars; and the tendency for the reduction of the trigonid basins, the tendency for p^4 and p^3 and the corresponding lower teeth to become bicuspid; the incipient development of a bony postorbital partition; the lateral expansion of the base of the braincase; the development of a tubular external auditory meatus; and the tendency for the angle of the mandible to be expanded and for its posterior border to become very large and rounded. Thus NECROLEMUR and MICROCHAERUS have advanced far from the primitive tarsioid type and indicate some of the structural stages through which the actual ancestors of the Old World series probably passed.

20. PRE-CATARRHINE, or SUPER-TARSIOID STAGE. Represented by PARAPITHECUS of the lower Oligocene of Egypt.

Food habits insectivorous-frugivorous.

Dental formula: $I\ \frac{?}{2}\ C\ \frac{?}{1}\ P\ \frac{?}{2}\ M\ \frac{?}{3}$

Lower incisors partly procumbent, not specialized.

Lower canine small, slightly larger than incisors and anterior premolars.

p^1, p^2 and p_1, p_2, lost; p^3, p^4 and p_3 and p_4, retained; the latter incipiently bicuspid. Posterior premolars becoming unlike molars, losing the incipiently molariform pattern of earlier mammals.

Lower molars with low, conical cusps, the talonid about as high as the trigonid. Paraconids lost, the four remaining cusps grouped into two pairs. Hypoconulids or mesoconids present.

The construction of the lower molars indicates that the upper molars were quadrate, with the anterior and posterior cusps arranged in two pairs.

Body of mandible and ascending ramus not so broad as in later members of the anthropoid-man series.

Skull unknown.

The direct derivation of PARAPITHECUS and the Old World series not known. The tarsioids foreshadow them in certain respects, such as the loss of the anterior two premolars, but all known tarsioids are excluded from direct ancestry by specialization of the front teeth, of the orbits, and of the lacrymal region. Nevertheless it is probable that the unknown predecessors of PARAPITHECUS might be included in a widened definition of the Tarsioidea.

21. PRIMITIVE ANTHROPOID STAGE. Represented by PROPLIOPITHECUS of the Lower Oligocene of Egypt.
Food habits frugivorous-omnivorous.
Dental formula: $I\frac{2}{2}\ C\frac{1}{1}\ P\frac{2}{2}\ M\frac{3}{3}$
Incisors not specialized; canines considerably larger than incisors, but crown of lower canine not very high.
Premolars bicuspid; molars with four main cusps arranged in two pairs; hypoconulids median.
The dentition of PROPLIOPITHECUS is structurally ancestral to that of all the higher apes and man, as noted by its discoverer, Schlosser.

22. ADVANCED PRE-HUMAN ANTHROPOID. Middle Tertiary. Represented by SIVAPITHECUS and DRYOPITHECUS. Miocene of India and Europe.
Food habits frugivorous-omnivorous.
Dental formula: $I\frac{2}{2}\ C\frac{1}{1}\ P\frac{2}{2}\ M\frac{3}{3}$
Lower incisors with crowns not widely expanded.
Lower canine with pointed, erect tip.
Lower anterior premolar with slightly flattened antero-external face, articulating with large upper canine. Posterior premolars bicuspid.
Lower molars with four main cusps arranged in two pairs; stout median hypoconulids.
Lower molars with "Dryopithecus pattern;" paraconids absent; trigonid basins reduced, talonid basins expanded. Upper molars m^1 and m^2 quadritubercular.

23. HUMAN PRECURSORS. Pliocene. PITHECANTHROPUS of the Pliocene or Lower Pleistocene (?) of Java possibly a representative. Skull top of very low type, much like a greatly enlarged gibbon skull. Forehead extremely low and retreating, supraorbital tori protruding far in front of narrow frontal region.
Two upper molars found in same stratum but further down stream and referred to individual represented by skull top.
Third upper molars very large, of advanced anthropoid or primitive human type.

24. HEIDELBERG RACE. Lower or Mid-Pleistocene, Europe.
Mandible of great size, with very massive body, very broad ascending ramus and backwardly-sloping chin. Dentition of primitive human type with tips of incisors and small canines on same level with premolars and molars.
Molar-cusp formula: $\bar{5},\bar{5},\bar{5}$

Molars moderately taurodont.
Skull probably of pre-Neanderthal type.

25. Low Human Type. Example: the "Mousterian youth."
Skull large, with very low forehead, dolicho, with great supraorbital tori, and very large prognathous face, with enormous platyrrhine nose. Chin retreating. Skull narrow anteriorly and broad posteriorly.
Incisors with edge-to-edge bite.
Molar teeth moderately taurodont. Premolar- and molar-crown patterns retaining many simian or primitive details. Second lower molars with five cusps and "Dryopithecus pattern." Second upper molar with four cusps, projecting hypocone.

26. High Human Type. Example: Homo Sapiens Nordicus.
Skull with steep forehead, secondarily (?) dolicho, with no supraorbital tori.
Face orthognathous, long, with delicate, straight, narrow nose.
Chin prominent. Incisor overbite.
Molar teeth short-crowned. Second lower molar with four cusps and +-shaped pattern. Second upper molar with three cusps, i.e., hypocone greatly reduced or absent. Third upper and lower molars greatly delayed in eruption, often failing to erupt at all.

VI. APPENDIX

MELANESIAN DENTITION WITH RESPECT TO OCCLUSION

1. Problem

In 1921 Hellman[181] challenged the etiology of Angle's Class II malocclusial manifestations with these findings:

"The examination of 354 children, both boys and girls, ranging in age from 3 to 15 years, revealed the fact that 71 or 19.94 per cent were breast-fed, 86 or 24.17 per cent were bottle-fed, and 199 or 55.89 per cent were breast-fed for a short time (from a few days to about six weeks), and later had to resort to the bottle. Both the bottle-fed and breast-fed-and-bottle-fed numbered 285 or approximately 80 per cent. Normal occlusion of the teeth among these children existed to the extent of 3 per cent, while 97 per cent had various forms of malocclusion."

[181] Hellman, 26; p. 11.

This seemed to be at variance with Angle,[182] who ascribed mouth-breathing and its attendant abnormalities, adenoids, etc., as causes of his Class II. Obviously there must be, closely linked with the feeding process, a factor other than mouth-breathing, if Hellman's data are to be accepted. In other words, we must, says Hellman, look to the problem of nutrition (breast-fed) and malnutrition (bottle-fed) to find the criteria of Class II.

TABLE 23

Melanesian dentition

A. Bite

GROUP	NUMBER			PERCENTAGE		
	Edge-to-edge	Over	Doubtful	Edge-to-edge	Over	Doubtful
New Guinea	10	8	9	37.0	29.7	33.3
New Britain	26	11	13	52.0	22.0	26.0
New Hebrides	4	2	0	66.7	33.3	—
Total (83)	40	21	22	48.2	25.4	26.4

B. Occlusion

GROUP	NUMBER						PERCENTAGE					
	Normal	Buccal	Mesial	Lingual	Distal	Doubtful	Normal	Buccal	Mesial	Lingual	Distal	Doubtful
New Guinea	24	0	1	1	0	1	88.9	—	3.7	3.7	—	3.7
New Britain	38	3	1	0	3	5	76.0	6.0	2.0	—	6.0	10.0
New Hebrides	4	0	0	0	1	1	66.7	—	—	—	16.6	16.7
Total	66	3	2	1	4	7	79.6	3.6	2.4	1.2	4.8	8.4

The writer, upon studying Hellman's work, was so impressed with it, that he discussed it at some length with Dr. Fay-Cooper Cole, who already had emphasized its importance. The result of the discussion was the writer's attempt, hereinafter noted, to check up Hellman's work.

[182] See p. 27 of this paper. Also Angle, 11; pp. 57–8.

TABLE 24

Melanesian dentition (with reference to occlusion)

SPECIMEN NUMBER	BITE	OCCLUSION	REMARKS
New Guinea			
43566	—	Mesial	—
43568	Square	Normal	—
43569	Square	Normal	—
43567	Over-bite	Normal	—
43606	—	Normal in buccal	Incisors and canines missing
43776	Square	Normal	All I and C missing
43510	Square	Normal	All upper teeth gone; all lowers gone, but molars; M_3 both sides erupted at right angle to M_2; very shallow notch.
43507	Square	Normal	All I and C missing.
43576	Over-bite (?)	Normal	No lower jaw; I^1 and I^2, left, and I^1, right, gone
43433	Square (?)	—	No lower jaw; I^1 both sides gone; molars worn evenly
43590	Over-bite	Normal	—
43591	Square	Normal	—
43537	Over-bite	Normal	—
43536	Square	Normal	Only upper and lower molar present
43495	Over-bite (?)	Normal	No lower jaw
43476	Over-bite	Normal	No lower jaw
43477	Over-bite	Normal	No lower jaw
43474	Over-bite	Normal	—
43454	Over-bite (?)	Normal	All lower I and C gone
43580	Over-bite (?)	Normal	No lower jaw; all upper I and C gone
43578	Square	Normal	No lower jaw; no upper I
43560	Over-bite	Lingual	—
43593	Over-bite (?)	Normal	No upper or lower I or C
43594	Square	Normal	Pronounced alveolar prognathism; all upper I procumbent
43609	Over-bite	Normal	—
43514	Square	Normal	—
43356	Over-bite (?)	Normal	No lower I or C
New Britain			
43223	Square (?)	Normal in buccal	All I and C gone
43220	Square (?)	Normal in buccal	All I and C gone; all lower molars 5-cusped
43135	Square	—	All I and C gone
43137	Square	Mesial	—

TABLE 24—*Continued*[*]

SPECIMEN NUMBER	BITE	OCCLUSION	REMARKS
New Britain —Con.			
43136	Square	Distal	I_1 left, and I_2 and I_2 right, gone
43134	Square	Buccal	(Mandible present not belong to skull); all upper I and C gone
43121	Over-bite	Normal	M_3 left not erupted
43146	Square	Normal	—
43147	Square (?)	Normal	—
43148	Square	Normal	All C, left, gone
43202	Square	Normal	All lower I and C gone
43191	Square	Normal	—
43224	Square (?)	Normal	All I and C gone
43209	Square (?)	Normal	All I and C gone, except C^1, right
43210	Square (?)	Unilateral distal	All molars but M_1, left, gone
43290	Square	Normal	All lower I and C gone
43296	Square	Normal (?)	Mandible, only, used here
43294	Over-bite	Normal	—
43292	Over-bite	Normal	—
43263	Over-bite	Normal	—
43216	Square	Buccal	—
43194	Over-bite	Normal	All lower I and C gone
43192	Over-bite	Normal	All upper I and C gone
43141	Over-bite	Normal	All upper I and C gone, except C, left
43142	Square	Normal	—
43143	Over-bite (?)	Normal	All upper I and C gone
43238	Square (?)	Normal	All I and C gone
43272	Square (?)	Normal	No jaw; all upper I and C gone; premolars and molars worn evenly
43180	Square (?)	Normal	Extra PM_1 right and left; two extra PM^1 left
43181	Square	Buccal	All upper I and C gone
43171	Square	Normal	—
43258	Square (?)	Normal (?)	No lower jaw; all upper I, C, and PM gone
43255	Square	Normal	No lower I and C
43156	Square	Normal	No lower I and C
43158	Over-bite	Normal	—
43159	Square	Normal	—
43157	Square	Normal	—
43130	Square	Normal	No upper I or C; all lower I and C, but C_1, left, missing

[*] Concluded on the succeeding page.

TABLE 24—*Continued*

SPECIMEN NUMBER	BITE	OCCLUSION	REMARKS
New Britain —Con.			
43131	Square	Normal	All upper and lower I and C, but C^1, right, missing
43151	Over-bite	Normal	—
43155	Square	Normal	—
43152	Over-bite	Normal	—
43154	Square	Normal	—
43176	Square	Normal	—
43173	Square	Normal	All upper right teeth gone
43177	Square	Normal	All upper I and C gone
43244	Square (?)	Distal	All upper I and C, except C left, and all lower I gone
43245	Square (?)	Normal (?)	All I and C gone
43284	Square	Normal (?)	No lower jaw; all upper I and C gone; molars worn evenly
43285	Over-bite	Normal	No I or C present
New Hebrides			
43025	Square	Normal	All I and C gone
43026	Over-bite	Distal (?)	All anterior teeth gone, but I^2 left
43037	Square	Normal	—
43017	Square	Normal	No lower jaw
43063	Square	Normal	No lower jaw
43052	Over-bite	Distal	—

2. Method

Under the direction of Dr. Cole, the writer observed the dentition of a series of some 317 Melanesian skulls. Of these 83 were accepted as offering sufficient evidence (i.e., enough teeth present) to offer a basis for adequate observation. In the examination of these teeth Angle's[182] definition of the various types of occlusion (i.e., mesial, distal, etc.) was accepted. As far as could be ascertained from an examination of the teeth present, it was noted whether the occlusion was normal, mesial, distal, etc. In addition the bite—edge-to-edge or over-bite—was noted. The Melanesian skulls were studied on the assumption that, should they reveal little or no malocclusion, we

must admit artificial food as a prime cause of malocclusion, as opposed to Angle's mouth-breathing. These Melanesian skulls presumably represent individuals who have, as infants, been raised on mother's milk, for the period of nursing among these people, and among primitive people in general, is about three years. On the other hand, should much evidence of malocclusion be found in these breast-fed cases, then obviously, Hellman's bottle-feeding must be subordinate.

3. Conclusions

The results of the study, both as to bite and occlusion, are shown in *Tables 23* and *24*. They lead to the following conclusions:

1. The groups studied (New Guinea, New Britain, New Hebrides) representing 83 cases reveal 79.6 per cent normal occlusion, and 4.8 per cent distal occlusion coming under Angle's Class II. The remainder, or 15.6 per cent, were distributed among mesial, lingual, doubtful, etc.

2. These groups, representing individuals raised on mother's milk, present a much higher rate of normality and corresponding lower rate of abnormality, with special reference to Angle's Class II, than do the cases where bottle-feeding is practised.

3. Therefore, it must be concluded that Hellman is correct in stating that bottle-feeding is an important cause of Angle's Class II malocclusion. And, it must be further concluded, that Angle's mouth-breathing as a cause is far from being an adequate explanation.

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VIII. ADDENDUM

Since this paper was submitted to the First District Dental Society, several additional articles on the human dentition and teeth have appeared, of which the outstanding contribution has been that of Gregory and Hellman, on "The dentition of *Dryopithecus* and the origin of man."[183] This memoir deals with the comparative data of the

[183] *Anthrop. papers*, AMNH, N. Y., V. 28, Part I, pp. 1–123; 1926.

recently discovered Siwalik types of *Dryopithecus;* summarizes the critical interrelationships of the several species of *Dryopithecus* and allied genera; presents a graphic tabulation of the lower dentition of *Dryopithecus*, modern anthropoids, and man; and offers an elaborate account of the origin of the human dentition.[184] As a result of their study the authors conclude that "from some form of *Dryopithecus*, possibly related to *D. rhenanus*, man has inherited his dental formula, the 'bicuspid' pattern of the upper and lower premolars, the 'Dryopithecus pattern' of the molars, many details of the incisors and the canines, and many important characters of the deciduous dentition."

The same authors, in their paper on "The crown patterns of fossil and recent human molar teeth and their meaning," present a series of questions to emphasize the thesis "that man and the modern anthropoids, in spite of widely divergent specializations, have inherited their innumerable structural and physiological correspondences from some very primitive and early member of the anthropoid group of Old World Primates."[185]

Three writers, Connolly,[186] Wolfson,[187] and Broadbent,[188] have undertaken a study of Simon's "orbital plane," and, working independently and with different techniques, have concluded that such a "plane" cannot be taken as an absolute criterion of perfect occlusion.

Another paper worthy of note is that of Variot, who presents a table on the eruption of deciduous teeth which is much like that of Kölliker's in his "Embryology"[189] (page 108).

[184] See also Gregory: "Ten structural stages in the evolution of the cheek teeth," *AJPA*, V. 9, pp. 401–26; 1926. Gregory: "Some critical stages in the evolution of the human dental apparatus," *JDR*, V. 6, pp. 71–100; 1924–6. The former paper offers a good account of the "premolar analogy" theory. In "*Natural History*," V. 27, p. 187, there is mention of a paper, by Gregory and G. G. Simpson, on some Cretaceous mammal skulls from Mongolia, describing the first good Mesozoic mammal skulls ever found.

[185] *Nat. Hist.*, V. 26, pp. 300–10; 1926.

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[188] Broadbent, B. H.: "Investigations on the orbital plane," *Dental Cosmos*, V. 69, pp. 797–805; 1927.

[189] Variot, G.: "Influence du processus de la dentification sur l'accroissement ponderal et statural des nourrissons," *La Semaine Dentaire*, V. 8, pp. 627–35; 1926.

	Months
Lower middle incisors	6 to 8
Upper middle incisors	7 to 9
Upper lateral incisors	9 to 11
Anterior premolars	14 to 16
Canines	15 to 18
Posterior premolars	20 to 24

The foregoing, in the main, are representative of the material which has appeared since June, 1926. Much work has been done on the effects of nutrition, which, of course, is a vital factor in the growth of the teeth. With respect to the racial aspects of the teeth, comparatively little has been done.

August 19, 1927.

THE ORIGIN AND EVOLUTION OF THE HUMAN DENTITION

A Palæontological Review

BY

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Anthropological aspects of the human teeth and dentition. *Wilton Marion Krogman*, Ph.B., M.A. 1

The First District Dental Society of the State of New York awarded this paper the Morris L. Chaim Prize for 1925.

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